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Timber Bridge
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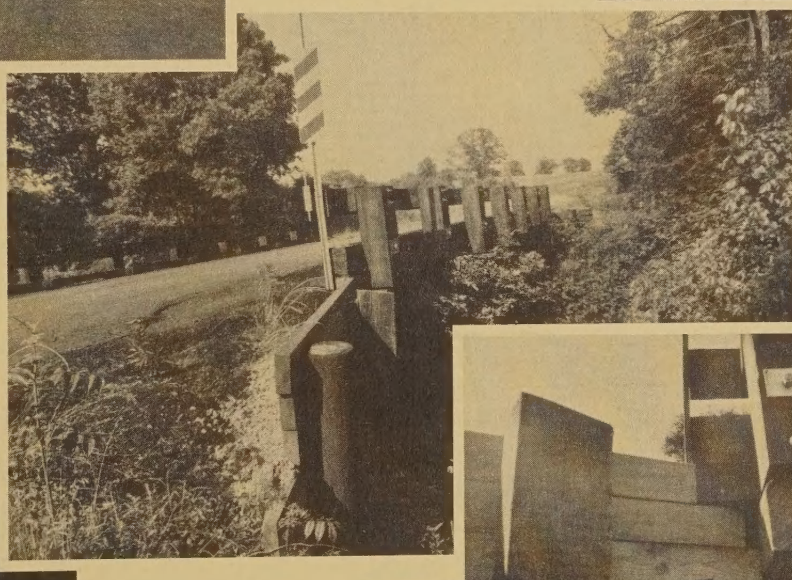
The Potential of Producing Prefabricated, Modern Timber Bridge Components in Mississippi

Mississippi Timber Bridge Program Marketing Study: Special Project Fiscal Year 1994



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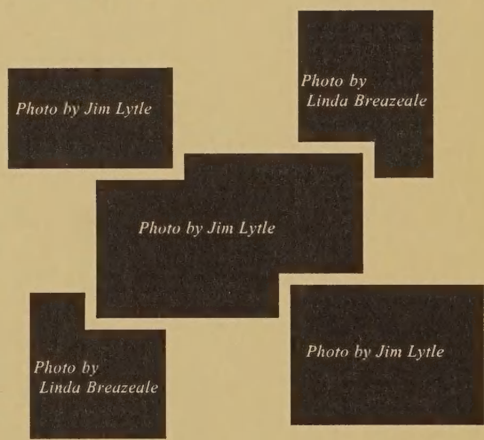

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Timber Bridge Information Resource Center

TECHNOLOGY
TRANSFER

Mississippi Timber Bridge Program
Marketing Study: Special Project Fiscal Year 1994

PREFACE

This publication is a technology transfer effort by the USDA Forest Service, Timber Bridge Information Resource Center in cooperation with the Mississippi Agribusiness Council. Funds for this project were made available through a grant from the USDA Forest Service.

This publication examines the potential of manufacturing prefabricated modern timber bridge components in Mississippi. Estimated manufacturing costs, estimated economic impact, and information supplemental to a detailed economic feasibility study are presented.

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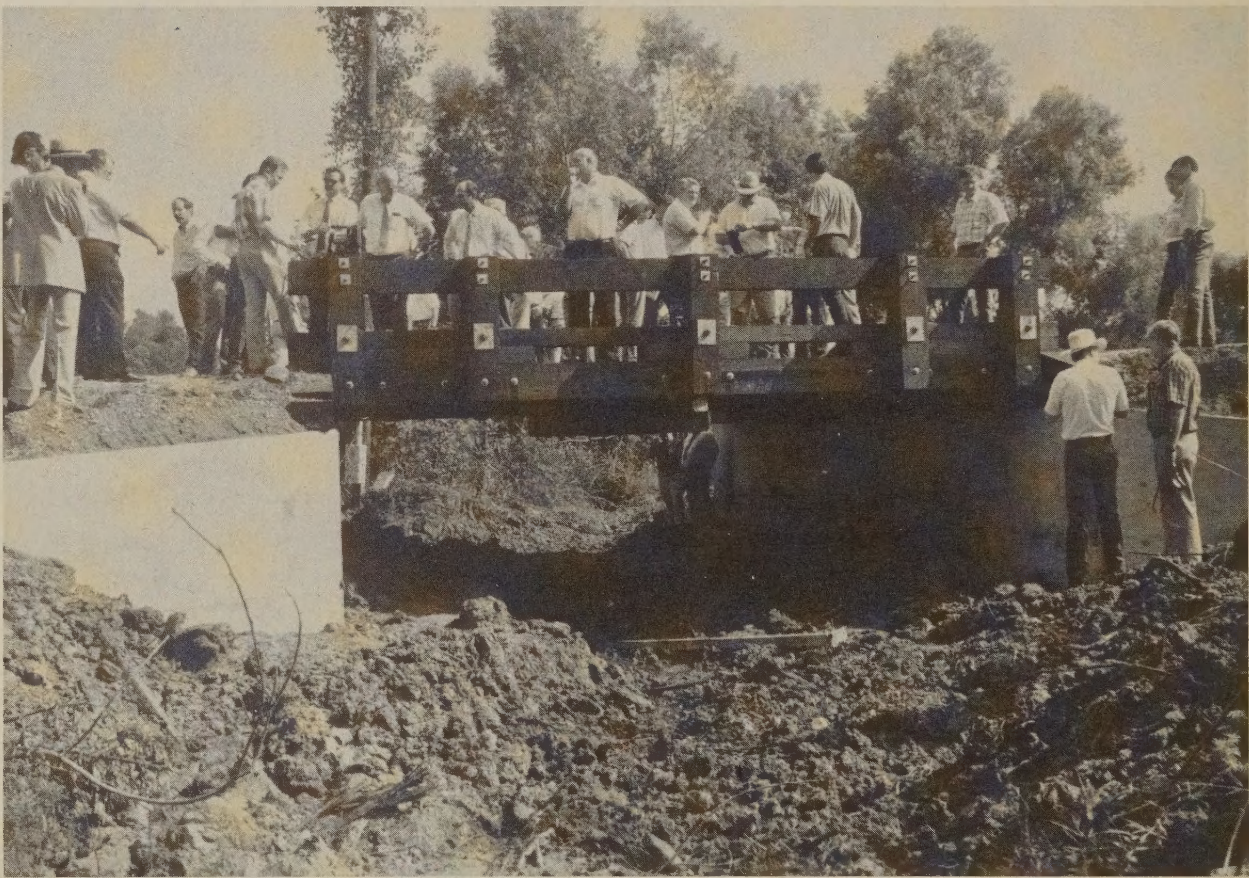
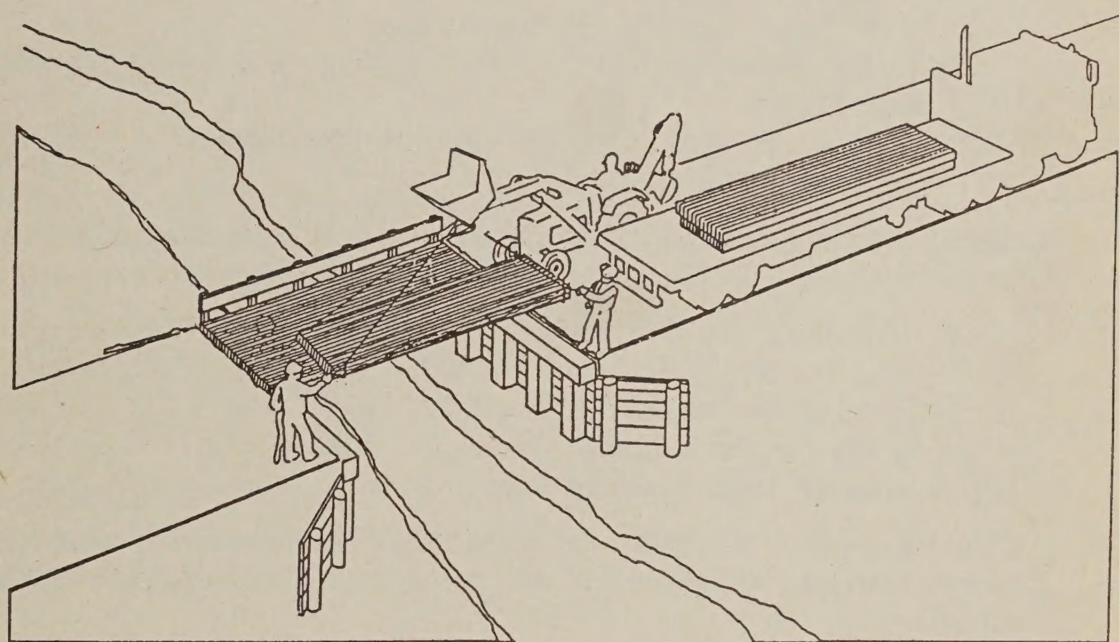


Photo by Linda Breazeale

The Potential of Producing Prefabricated, Modern Timber Bridge Components in Mississippi



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Mississippi Agribusiness Council

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Mississippi Agriculture and Forestry Experiment Station
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This report was prepared by a team of professionals from several departments and colleges at Mississippi State University. The project team included:

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Significant contributions were also made by Dr. Ken Hood, Economist, and Ms. Ann Sansing, Project Technician, Food and Fiber Center, Cooperative Extension Service.

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Photo by Jim Lytle

Executive Summary

This study examines the potential of manufacturing prefabricated, modern timber bridge components in Mississippi. Estimated manufacturing costs, estimated total economic impact, and information supplemental to a detailed economic feasibility study are presented.

Conclusions

Many Mississippians may expect this report to reveal that modern timber bridges are more cost effective than concrete bridges, or vice versa. The findings of this inquiry do not allow us to make such a statement for several reasons. First, the costs developed from the forest industry and compiled here are the best estimates of firms that have little or no experience building modern timber bridge components. Such prices cannot be compared to list prices of an industry that has been in production for years and has its manufacturing techniques refined. Secondly, bridge costs are very site specific, and average costs are not always meaningful where the costs of a particular bridge are concerned. Many factors affect the cost and ultimate selection of a bridge design. These factors include such things as soil conditions to support the bridge, and the length of time the road will be closed. No account of these factors could be made in this study.

We polled Mississippi's lumber industry and identified a set of realistic costs for which Mississippi firms can manufacture two types of prefabricated, modern timber bridge components. We also identified some institutional policy barriers that prevent modern timber bridges from competing in the Mississippi bridge market.

The ultimate answer about whether modern timber bridges are cost competitive in Mississippi will be answered by the market once competition between materials is allowed. It is expected that, over time, competition between bridge construction materials will cause the price of all materials to go down.

Summary

The subject of highway bridges is technical and complex, but it is also very important, especially to the state of Mississippi. Unfortunately, some aspects of the transportation infrastructure necessary to sustain Mississippi's economy are in disrepair. Specifically, 6,420 (39 percent) of the 16,489 bridges in Mississippi have sufficiency ratings of less than 50. Bridges are given sufficiency ratings in accordance with the National Bridge Inspection Standards. Bridges with a sufficiency rating less than 50 cannot support the full designed loads and need to be replaced.

It is estimated that there are an additional 2,800 bridges in Mississippi that are classified as functionally obsolete, meaning they can carry the designed loads, but should be replaced because of other considerations. A functionally obsolete bridge, for example, may be too narrow to be safe, or it may have an insufficient opening underneath to accommodate current drainage in the area.

State leaders have described Mississippi's bridge system as being in need of major and immediate improvement for the safety of our citizens, the development of our agricultural and industrial commerce, and for the enjoyment of our state's natural beauty. Mississippi needs to improve its bridge infrastructure for sustained, economic growth.

New technology in modern timber bridges is emerging and being demonstrated nationwide. Many other states are taking advantage of the opportunities that now exist with the utilization of such bridges. In recent years, several modern timber bridges have been built in Mississippi as demonstration bridges using special funds.

Market penetration is a major factor in determining the feasibility of any new manufacturing facility. Of the estimated 9,220 bridges in Mississippi that need to be replaced or rehabilitated, over 50 percent have short spans between 20 and 60 feet. Although this is the span range most suitable for modern timber bridges, this market is essentially unavailable because of obstacles that limit consideration of these bridges as a viable alternative when building, replacing, or repairing a bridge in Mississippi. Some of the major needs for development of a modern timber bridge industry in Mississippi include:

- Allow modern timber bridges to compete for State Aid bridge improvement funds.
- Acquire expertise on modern timber bridge design and construction within the Mississippi Department of Transportation and Office of State Aid Road Construction.
- Adopt standard drawings with associated specifications for modern timber bridges within the Mississippi Department of Transportation and Office of State Aid Road Construction.
- Increase awareness of the advantages of modern timber bridge technology by state and county officials.
- Change the negative image of modern timber bridges based on experiences with "old style" timber bridges.
- Establish manufacturers of modern timber bridge components in Mississippi.

If a modern timber bridge manufacturing industry could be established and developed, it is possible that Mississippi could also tap markets in other states and countries (e.g., Mexico).

Although there are many different structural designs for modern timber bridges, two basic designs were chosen to estimate costs for bridge components in this study. Costs for a dowel laminated bridge deck design suitable for spans of 18 to 28 feet with HS 20-44 loading ranged from $17.25 to $33.42 per square foot, respectively. Costs for a Glulam bridge deck design suitable for spans of 30 to 50 feet with HS 20-44 loading ranged from $29.28 to $34.69 per square foot, respectively. These costs do not include guard rails, delivery, or erection costs. These estimated costs are for a currently nonexistent industrial fabrication facility and, therefore, could decrease as an industry develops and becomes established.

A major advantage of modern timber bridges is their lighter weight compared to traditionally-constructed bridges. Thus, modern timber bridges can be used for spans in excess of 100 feet without the generally associated high costs of supporting substructure and erection labor normally required with other bridge construction materials.

The overall cost of erected modern timber bridges was not included in this study because of the high degree of dependency on the geotechnical characteristics of bridge sites.

The selected total linkage multipliers used to estimate the economic impact of the proposed manufacturing industry are 1.99, 1.95, and 1.93 for output, income, and employment, respectively. This implies that for every 10 people that are hired to operate the facility, 9 others would be hired indirectly in support or supply industries. For every $1,000 paid in wages by the new facility, $950 in other, indirect wages would be generated in the state economy. Likewise, if $2,000,000 in sales is produced the first year by the new company, an indirect output of an additional $1,980,000 would be generated in the state economy.

Investment and operating costs for a proposed prefabricated, modern timber bridge component manufacturing plant would need to be determined on an individual basis because of the many different manufacturing possibilities that exist. Included is one model of such a facility for Mississippi. The model presented shows estimated investment and associated operating costs for a typical manufacturing facility producing prefabricated, dowel laminated modern timber bridge components. Costs for five different annual production capacities were estimated. As output increased from 120 to 200 bridges annually, the production cost per square foot decreased from $25 to $18, respectively. Included as an addendum is a discussion of several related economic aspects of the existing concrete bridge industry in Mississippi (Appendix B).

Some of the major advantages of modern timber bridges are:

- Quick and easy bridge erection by local county crews, thus reducing road closure time, labor, and equipment costs.
- Simple designs engineered to site specifications, making them environmentally compatible and aesthetically pleasing.
- Unaffected by freezing temperatures, and surprisingly fire resistant.
- Uniquely resilient to dynamic impact loads, earthquakes, and tornadoes.

Some of the disadvantages are:

- Lack of definitive data regarding service lives and maintenance costs preclude a life-cycle cost study.
- Asphaltic wearing surfaces require special attention and consideration.
- If not properly installed and maintained, they can be susceptible to insect attack and decay.

Availability of raw materials and initial processing facilities are other major factors in determining the feasibility of a manufacturing operation. The primary input for the proposed prefabricated, modern timber bridge component manufacturing operation is timber.

Mississippi has about 17 million acres of commercial forest land which consists of approximately 42 percent pine and 58 percent hardwood. Some of the highest quality southern yellow pine timber available is located in Mississippi. There are over 180 sawmills in the state, 66 of which are pine sawmills. There are over 20 wood preservative treating facilities in Mississippi. Mississippi's forest products industry is a major manufacturing employer. These firms provide nearly one in every four manufacturing jobs in the state – 61,000 in 1991.

The forest products industry is Mississippi's leading agricultural sector, with an estimated value of $972 million in 1993 at the first point of processing only. It appears that Mississippi has the timber resource and existing industrial base to build and support the proposed modern timber bridge industry.

Mississippi's major softwood species is southern yellow pine, which is an ideal material for use in modern timber bridges. Not only does southern pine have favorable strength characteristics, but the large body of information that exists about its anatomy, physical and mechanical properties, machining and gluing characteristics, and treatability, permits engineers to design and construct bridges for use in a variety of settings. It provides an opportunity for technological innovations applied to modern timber bridge construction.

No structure should be built without provisions for periodic inspection and maintenance, and timber bridges are no exception. Field personnel need to be trained to make periodic inspections and to determine maintenance needs. This study contains a detailed discussion of proven timber bridge inspection techniques and maintenance procedures. All bridges should be inspected by trained personnel on a regular basis (e.g., one to five years). If one-fifth of the bridges in a county were inspected every year, no bridge would go without an inspection for more than five years.

The preparation and development of educational information on the use of modern timber bridge components is beyond the scope of this study. However, a suggested format for disseminating such information is included.

Rural bridges adequate for the passage of heavy trucks are considered to be vitally important to Mississippi's agricultural and rural economy. Simple, lightweight, and quickly constructed bridges and bridge components are a major consideration for making the needed improvements. The thrust of the National Modern Timber Bridge Initiative by the USDA Forest Service is focused on these aspects. Recent efforts have concentrated on establishing and promoting the durability and longevity of modern timber bridges to ensure their consideration as a viable alternative for improving rural bridges. In addition, adoption of modern timber bridges as an alternative will encourage competition among materials for bridge construction. Such competition should theoretically lower costs of all bridge materials. But, for Mississippi to take advantage of the opportunities that exist for a modern timber bridge manufacturing industry, the state must provide the technical support and the means for their consideration as a viable alternative when local bridge decisions are made and funds are obligated.

Many states across the United States have been exploring and using modern timber bridges. Mississippi should capitalize on every new technology that can help improve our bridge and transportation infrastructure. Furthermore, an investment in the research and development of innovative designs and manufacturing techniques of prefabricated, modern timber bridge components is timely. It will lead to competitive alternatives to the presently-used structural materials in bridge construction.

Introduction

Mississippi is fortunate to have an abundant supply of high-quality hardwood and softwood timber. This is a natural renewable resource suitable for use as a raw material for producing prefabricated, modern timber bridge components. Modern timber bridges have been shown to be economical and effective in other states (Behr, 1990; Weyerhaeuser, unpublished). Unfortunately, whether or not private industry in Mississippi could provide competitively priced modern timber bridge components to satisfy the potential market demands at a reasonable profit margin is not known. If profitable, this new Mississippi industry would have a substantial direct and indirect economic impact on the state's economy through an increased employment and tax base. The overall impact, however, is undetermined. Ironically, the Mississippi wood products manufacturing industry, the state's largest- and fastest-growing manufacturing sector, is dependent on a good transportation infrastructure for transporting both raw materials and finished products.

Although state-of-the-art technology is available for timber to be successfully used as a modern timber bridge building material, previous misuse of treated wood for "old style" timber bridge construction has created, among some engineers, a negative impression for timber as a durable construction material. For prefabricated, modern timber bridge components to compete in the market place, decision makers need to be informed of the many advantages of this new construction technique. State and county engineers and county board supervisors are some of these decision makers.

As a result of the major initiative by the 1994 State Legislature to appropriate funds for bridge replacement and repair, and the potential for substantial economic impact to the state's manufacturing sector, the Mississippi Agribusiness Council requested that a project team examine the potential of manufacturing prefabricated, modern timber bridge components in Mississippi. A project team was formed, and this report is the result of that request.

Goals and Objectives

This project had the following objectives:

1. Determine the economic feasibility of producing prefabricated, modern timber bridge components in Mississippi.

2. Determine the total economic impact of a prefabricated, modern timber bridge component industry to the economy of Mississippi.

3. Provide information for the development of educational materials describing the advantages and disadvantages of utilizing modern timber bridges as an alternative material for bridge construction or replacement in Mississippi.

Status of Mississippi Bridges

Data from the Mississippi Department of Transportation and Office of State-Aid Road Construction indicated that there are 16,489 bridges in Mississippi. For this report, a bridge was included if the span between abutments was equal to or greater than 20 feet. Of the 16,489 bridges, 6,420 (39 percent) had a sufficiency rating of less than 50. Bridges with a sufficiency rating of less than 50 cannot support the designed standard load, need to be replaced, and in the interim, need to be posted for limited loading. It is estimated there are an additional 2,800 bridges that are classified as functionally obsolete, meaning they can carry the designed load, but should be replaced because of other considerations. For example, a functionally obsolete bridge, may be too narrow to be safe, or it may have an insufficient opening underneath to accommodate current drainage in the area. Table 1 is a listing of data on Mississippi bridges for 1993. The distribution of deficient bridges by county across Mississippi is illustrated on Maps 1 and 2.

Distribution of Deficient Bridges

Every county in Mississippi has bridges with sufficiency ratings of less than 50. There is an average of 78 structurally deficient bridges per county in Mississippi ranging from three in Issaquena County to 168 in Panola County. In northeast Mississippi, there is a high concentration of counties with the largest number of structurally deficient bridges. Counties with a low number of structurally deficient bridges are generally located along the Mississippi River and in southeast Mississippi.

Although the scope of this report does not include a discussion on the topic of creating a system to prioritize a listing of counties with the greatest need for bridge repair or replacement, it is interesting to note the distribution of counties based on the percentage of bridges within the county that are structurally deficient. The distribution is illustrated on Map 2 and listed in Table 1. On the average, a Mississippi county has 40 percent of its bridges with a sufficiency rating of less than 50, ranging from 10 percent in Issaquena to 74 percent in Jefferson County. There are three areas within the state that have a high concentration of counties with percentages of deficient bridges. These areas are located in the extreme northern part of the state, the mid-central, and southwest areas of the state. Also, there does not appear to be a close correlation between the number of deficient bridges in a county to the population of the county. A disproportionate share of deficient bridges was not found in the most rural, or the most densely populated counties. Ten percent of the deficient bridges state-wide are located in nine of the most populated counties, and 25 percent of the deficient bridges state-wide are located in 24 of most rural counties in Mississippi.

The Space Remote Sensing Center, working with initial research done by Mississippi Automated Resource Information System, developed methods and techniques for a system to assist in prioritizing roads and bridges for maintenance or improvements using a Geographic Information System (GIS). The intent of the project was to demonstrate how a GIS can be used to show the most likely candidates based on models used in the project (Vernamonti, unpublished).

Deficient Bridge Lengths

Table 2 is a listing of bridge lengths for deficient bridges in Mississippi. The data are illustrated in Figure 1. Data on the lengths of deficient bridges were grouped in increments of five feet. Results show that of the 6,420 deficient bridges in Mississippi, 3,778 (59 percent) are between 20 and 60 feet in length. Only 1,368 bridges (21 percent) are over 100 feet in length. Clearly, Mississippi's bridge replacement needs are focused on the shorter span lengths. This is also illustrated in Figure 2 which shows the rather small increase in the cumulative number of deficient bridges when the lengths exceed 60 feet.

Historical Development of Timber Bridges

Wood was probably the first material used by humans to construct bridges. From prehistoric times through the Middle Ages, our ancestors adapted available materials, such as logs and vines, to span crossings. From the end of the Middle Ages through the 18th century, scientific knowledge developed and influenced the design and construction of timber bridges. In the 19th century, the sophistication and use of timber bridges increased in response to the growing need for public works and transportation systems associated with the industrial revolution (Ritter, 1990).

The changes that have occurred during the past two decades in timber engineering and construction methods have revitalized the use of timber as a structural framing material. The most evident impact of the changes can be found in the design and construction of roadway bridges. Successful implementation of manufactured timber components was demonstrated by assembling individual timber board elements into integral structural systems. Prefabricated timber components fastened together to provide a smooth roadway surface for bridge crossing signaled the birth of modern timber bridge construction in the late 1970's. This new industry is growing at a fast pace at the present time and affords tremendous potential for a new industry. The final outcome has been extremely satisfying to structural engineers (Ritter, 1990).

The prospects for introducing new, innovative, and structurally enhanced designs in modern timber bridge components are extremely good and are expected to occur at a fast rate in the next few years. Recently, the move to advance technologically the methods for using prefabricated timber components in the structural designs of bridges has been dynamic. The emphasis of current designs in timber bridge construction is to move from medium spans to longer spans. For example, recently a modern timber bridge was built in Alabama with a span of 110 ft. (Nixon, unpublished).

Table 1. Mississippi Bridge Data, 1993 (Sufficiency Rating Less than 50)[1, 2, 3]

COUNTY	TOTAL BRIDGES	NUMBER DEFICIENT	PERCENT DEFICIENT BRIDGES	COUNTY[3] POPULATION (x 1,000)	PERCENT[3] RURAL POPULATION
ADAMS	99	34	34	35.4	45.0
ALCORN	229	136	59	31.7	62.7
AMITE	249	140	56	13.3	100.0
ATTALA	239	144	60	18.5	62.2
BENTON	95	66	70	8.00	100.0
BOLIVAR	299	91	30	41.9	50.4
CALHOUN	231	137	59	14.9	100.0
CARROLL	239	141	59	9.2	100.0
CHICKASAW	231	127	55	18.1	60.4
CHOCTAW	126	57	45	9.1	100.0
CLAIBORNE	107	15	14	11.4	100.0
CLARKE	223	71	32	17.3	84.4
CLAY	161	83	52	21.1	59.8
COAHOMA	138	47	34	31.7	37.7
COPIAH	251	45	18	27.6	64.3
COVINGTON	160	46	29	16.5	84.6
DESOTO	163	36	22	67.9	47.0
FORREST	294	57	19	68.3	24.1
FRANKLIN	147	65	44	8.4	100.0
GEORGE	91	32	35	16.7	84.3
GREENE	140	33	24	10.2	100.0

Table 1. Mississippi Bridge Data, 1993 (Sufficiency Rating Less than 50)[1,2,3] (continued)

COUNTY	TOTAL BRIDGES	NUMBER DEFICIENT	PERCENT DEFICIENT BRIDGES	COUNTY[3] POPULATION (x 1,000)	PERCENT[3] RURAL POPULATION
GRENADA	139	63	45	21.6	49.6
HANCOCK	95	16	17	31.8	39.9
HARRISON	247	46	19	165.4	15.7
HINDS	578	101	18	254.4	13.3
HOLMES	260	113	44	21.6	86.8
HUMPHREYS	120	82	68	12.1	79.1
ISSAQUENA	30	3	10	1.9	100.00
ITAWAMBA	226	96	43	20.0	83.1
JACKSON	217	31	14	115.2	19.6
JASPER	187	39	21	17.1	100.0
JEFFERSON	84	62	74	8.7	100.0
JEFFERSON DAVIS	144	57	40	14.1	100.0
JONES	329	55	17	62.0	63.8
KEMPER	202	90	45	10.4	100.0
LAFAYETTE	275	136	50	31.8	68.6
LAMAR	170	102	60	30.4	73.4
LAUDERDALE	455	100	22	75.6	42.4
LAWRENCE	125	85	68	12.5	100.0
LEAKE	173	88	51	18.4	79.3
LEE	346	148	43	65.6	46.9
LEFLORE	146	38	26	37.3	49.4

Table 1. Mississippi Bridge Data, 1993 (Sufficiency Rating Less than 50)[1,2,3] (continued)

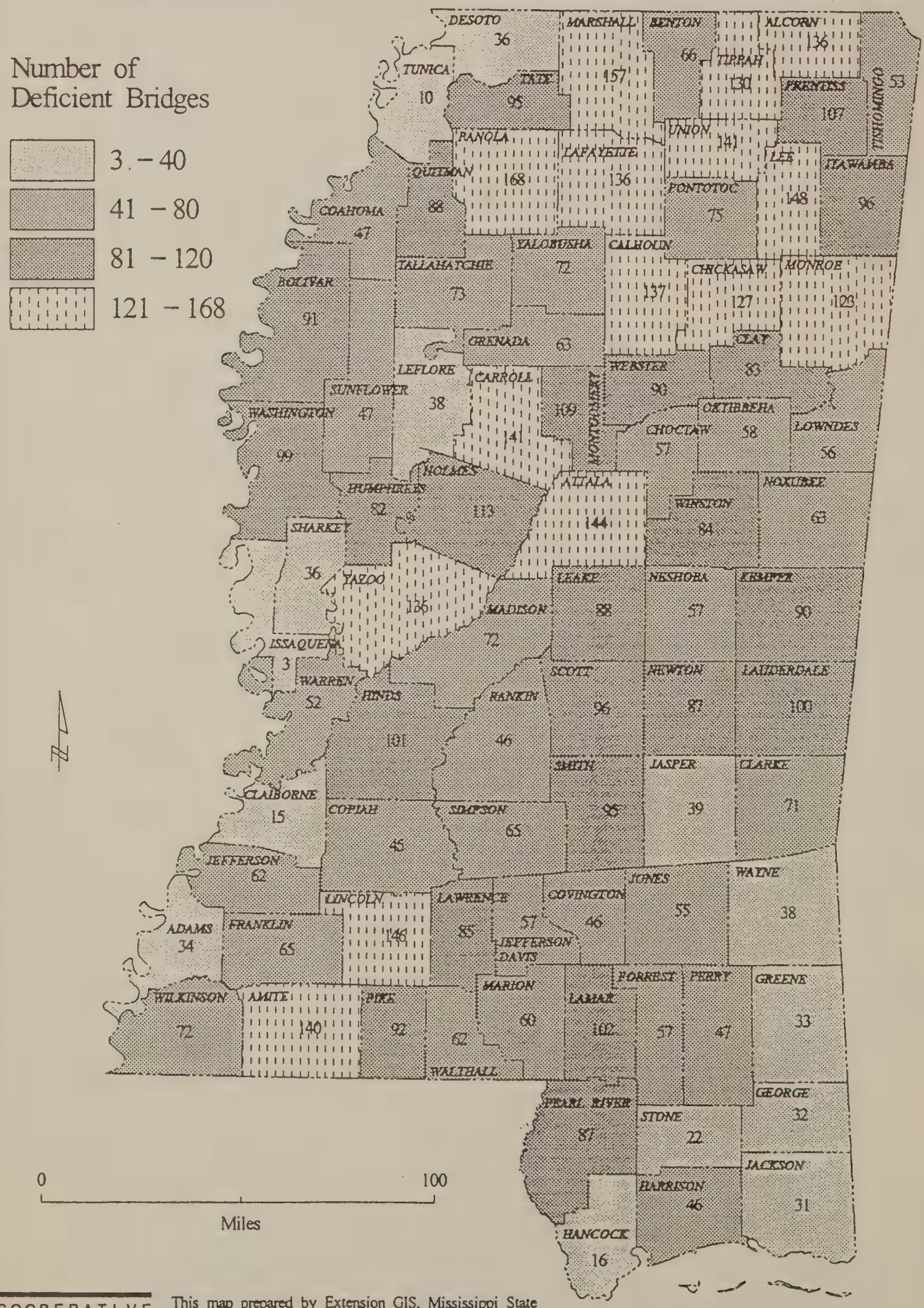
COUNTY	TOTAL BRIDGES	NUMBER DEFICIENT	PERCENT DEFICIENT BRIDGES	COUNTY[3] POPULATION (x 1,000)	PERCENT[3] RURAL POPULATION
LINCOLN	381	146	38	30.3	66.2
LOWNDES	215	56	26	59.3	55.0
MADISON	271	72	27	53.8	42.0
MARION	212	60	28	25.5	73.3
MARSHALL	241	157	65	30.4	76.1
MONROE	241	123	51	36.6	61.9
MONTGOMERY	193	109	57	12.4	53.9
NESHOBA	193	57	30	24.8	72.8
NEWTON	257	87	34	20.3	81.8
NOXUBEE	180	63	35	12.6	100.0
OKTIBBEHA	216	58	27	38.4	51.9
PANOLA	259	168	65	30.0	78.7
PEARL RIVER	239	87	36	38.7	65.6
PERRY	164	47	29	10.9	100.0
PIKE	250	92	37	36.9	68.6
PONTOTOC	163	75	46	22.2	79.4
PRENTISS	188	107	57	23.3	58.5
QUITMAN	136	88	65	10.5	100.0
RANKIN	303	46	15	87.2	45.5
SCOTT	209	96	46	24.1	65.7
SHARKEY	89	36	40	7.1	100.0

Table 1. **Mississippi Bridge Data, 1993 (Sufficiency Rating Less than 50)**[1,2,3] (continued)

COUNTY	TOTAL BRIDGES	NUMBER DEFICIENT	PERCENT DEFICIENT BRIDGES	COUNTY[3] POPULATION (x 1,000)	PERCENT[3] RURAL POPULATION
SIMPSON	193	65	34	24.0	84.9
SMITH	180	95	53	14.8	100.0
STONE	111	22	20	10.8	70.4
SUNFLOWER	206	47	23	32.9	54.3
TALLAHATCHIE	177	73	41	15.2	100.00
TATE	170	95	56	21.4	77.7
TIPPAH	180	130	72	19.5	72.5
TISHOMINGO	136	53	39	17.7	82.3
TUNICA	57	10	18	8.2	100.0
UNION	230	141	61	22.1	69.3
WALTHALL	157	62	40	14.4	100.0
WARREN	167	52	31	47.9	56.3
WASHINGTON	381	99	26	67.9	18.8
WAYNE	173	38	22	19.5	73.6
WEBSTER	162	90	56	10.2	100.0
WILKINSON	128	72	56	9.7	100.0
WINSTON	174	84	48	19.4	63.1
YALOBUSHA	164	72	44	12.0	70.0
YAZOO	283	136	48	25.5	51.3
TOTAL	**16,489**	**6,420**	**0**	**2,573.5**	**0**

[1]Source: Office of State Aid Road Construction
[2]Source: Mississippi Department of Transportation
[3]Source: Office of Planning and Research. Mississippi Institutions of Higher Learning

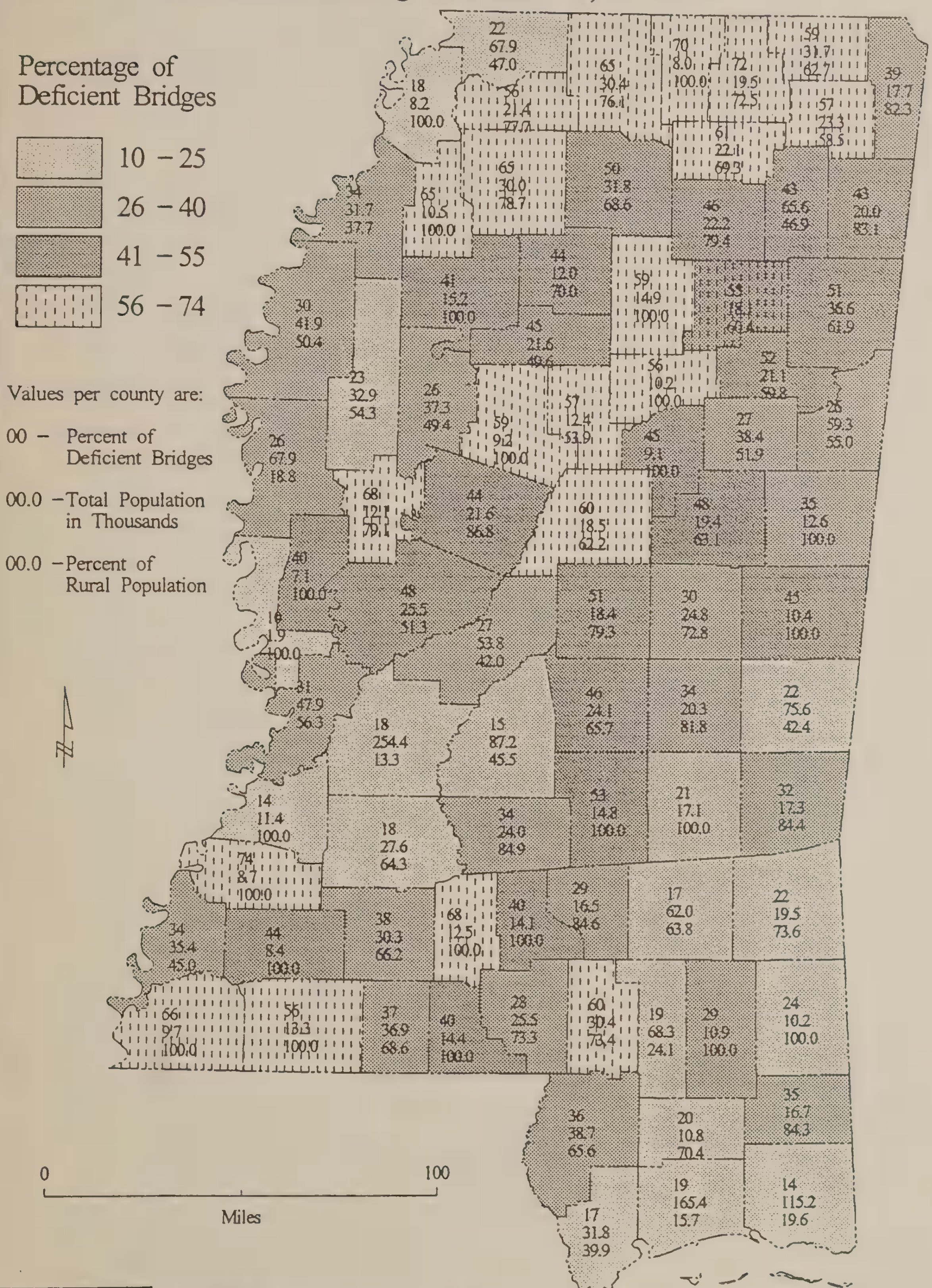
Map 1. Deficient Bridges Per County in Mississippi that Need Replacement, 1993 (Sufficiency Rating less than 50).



COOPERATIVE EXTENSION SERVICE

This map prepared by Extension GIS, Mississippi State University – Cooperative Extension Service. Extension GIS does not warrant its accuracy or completeness. Map prepared January 1994.

Map 2. Percentage of Deficient Bridges Per County in Mississippi, 1993 (Sufficiency Rating less than 50).



COOPERATIVE EXTENSION SERVICE

This map prepared by Extension GIS, Mississippi State University – Cooperative Extension Service. Extension GIS does not warrant its accuracy or completeness. Map prepared January 1994.

Table 2. Deficient Bridges By Length in Mississippi, 1993.
(Sufficiency Rating Less Than 50)

LENGTH	TOTAL
20-25	464
26-30	375
31-35	430
36-40	686
41-45	409
46-50	373
51-55	278
56-60	733
61-65	156
66-70	159
71-75	135
76-80	296
81-85	105
86-90	129
91-95	163
96-100	161
>100	1368
TOTALS	6420

Figure 1. Bridge Length of Deficient Bridges In Mississippi, 1993. (Sufficiency Rating Less Than 50)

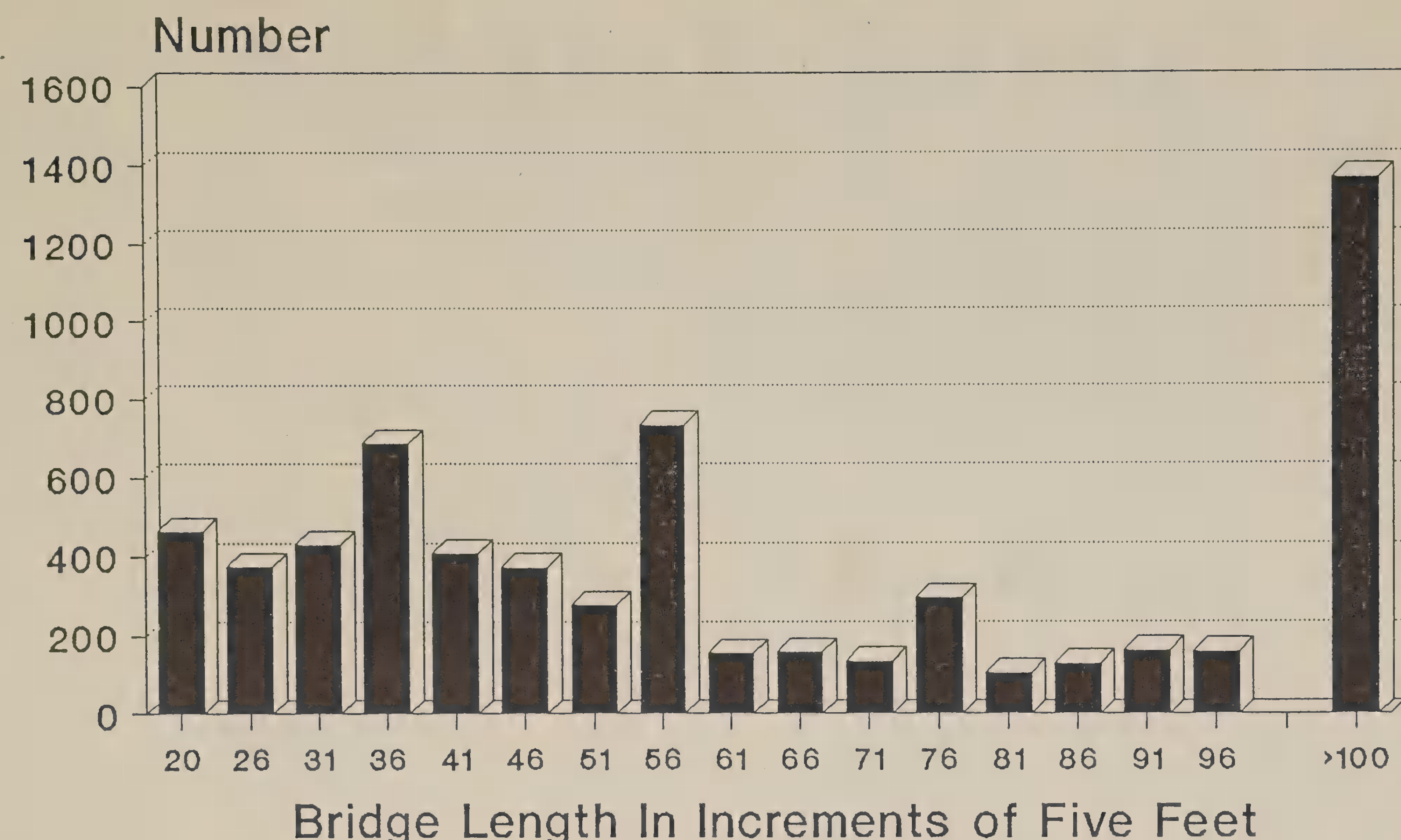
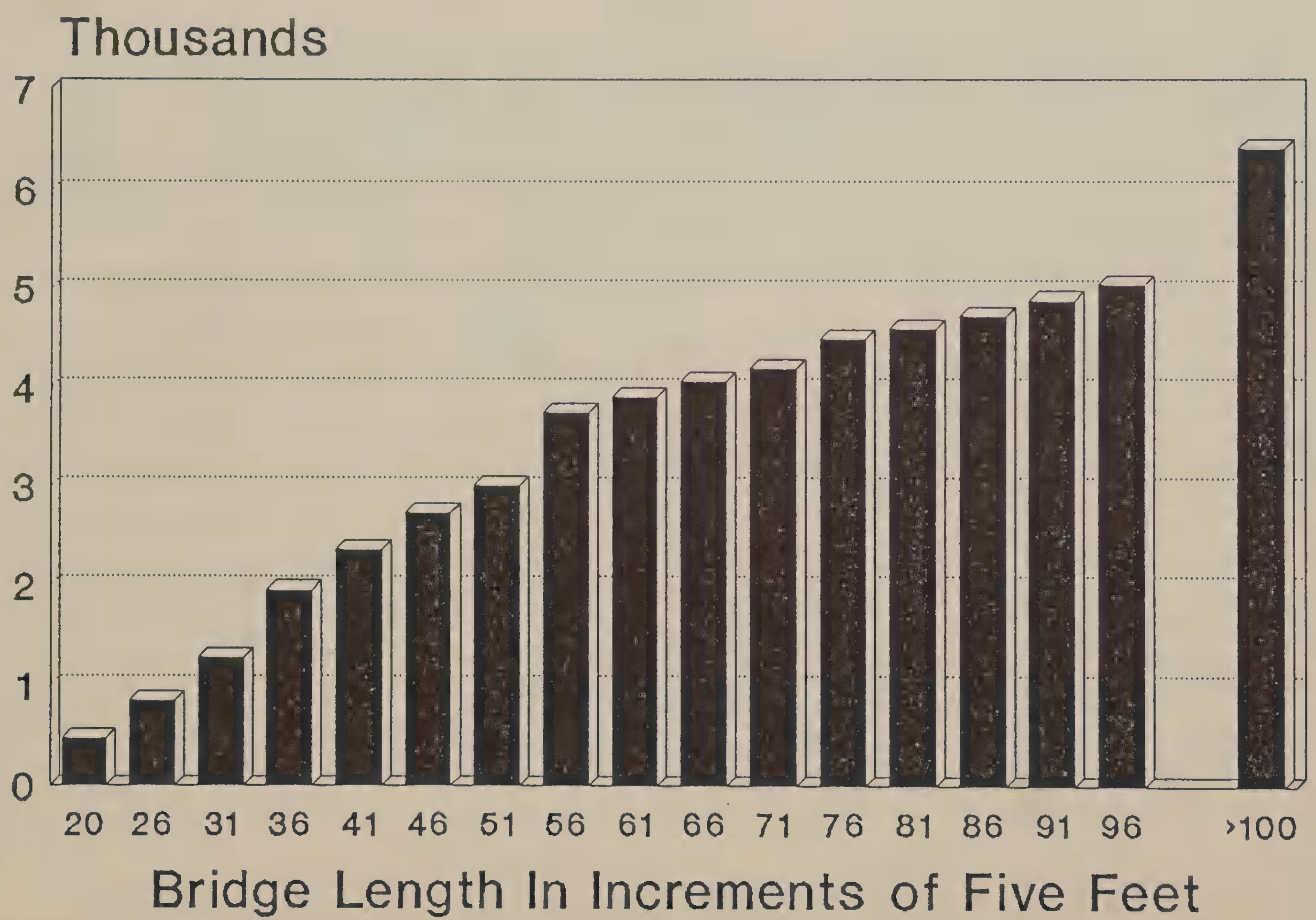


Figure 2. Cumulative Deficient Bridges In Missisippi, 1993. (Sufficiency Rating Less Than 50)



Modern Timber Bridges: A New Era in Bridge Development

For over 100 years, preservative-treated timbers have been used to build bridges. Such bridges were built on location from the ground up, similar to constructing a house. These techniques of construction were labor intensive, and protection of the treated timbers during construction was sometimes inadequate, creating problems later. Today a new generation of treated timber bridges has emerged, and a distinction must be made for the reader between the old type of timber bridge and the modern timber bridge.

Modern timber bridges can be defined as a prefabricated, timber bridge system, engineered using modern structural design, constructed of timbers treated to verified contemporary standards, and incorporating regular inspection and maintenance practices. Table 3 provides a point-by-point comparison of "old style" timber bridges and the modern timber bridge.

A major difference between modern timber bridges and the traditional timber bridges is that modern timber bridges consist of prefabricated components constructed in a factory and brought to the job site where they can be assembled quickly with a minimum of cutting or drilling. This is a significant improvement over traditional construction techniques because field cutting and drilling of treated timbers done in construction of "old style" timber bridges exposed untreated wood to the environment, sometimes resulting in the entry of decay fungi and eventual deterioration of the bridge member. Without regular inspection and maintenance, this deterioration resulted in not only a bridge needing repair, but also in a poor reputation for treated timber bridges among some engineers. Properly treated, constructed, and maintained timber structures can give long years of service.

The Illinois Central Gulf Railroad has rail lines that travel through Mississippi from Memphis to New Orleans, Louisiana, and Jackson to Mobile, Alabama. Along these routes, there are treated timber tressels that have been in service with no recorded repairs for over 70 years (Personal Communication, Daniels). The new thrust in modern timber bridge development includes many designs, and researchers are continuing to use treated timber in innovative designs and in combination with other materials. In this study, we focused on the dowel laminated, longitudinal timber decks design (Figure 3) and the glulam stringers and transverse panel deck design (Figure 4), but there are other innovative uses of timber for highway bridges.

A major innovation in design is the stress-laminated timber bridge. The stress lamination technique utilizes treated structural timbers, longitudinally oriented and stressed together using threaded steel stress rods passed transversely through the deck. The stress rods are placed 2 to 4 feet apart along the length of the bridge and are tensioned to form a continuous deck. Shorter timbers can be used in forming the stressed timber deck using the engineering strength properties of timber in a more cost-effective manner. Variations of the stress lamination technique include the simple stress laminated timber deck, stressed T-sections, stressed box sections, and others. Extensive research for innovative designs of modern timber bridges is rapidly continuing at the present time. This work is leading to innovations in structural systems, layout, assemblies, and fastening systems. One such innovation currently being tested at The Pennsylvania State University is the combination of timber and some steel longitudinal members in a stress laminated deck that promises to extend the clear span length of modern timber bridge systems.

Table 3. Comparison of "Old Style" Timber Bridges to Modern Timber Bridges

"Old Style" Timber Bridges	Modern Timber Bridges
1. Built using locally acceptable techniques.	1. Engineered systems of premanufactured technologically enhanced structural designs.
2. Timbers are cut and drilled in the field.	2. Wood members are cut and drilled prior to treating with preservatives. Field cutting is seldom required.
3. Treatment integrity not always assured.	3. Wood members are treated using state-of-the-art preservative systems and technology with assured preservative retention.
4. Minimal fabrication control of timber members with loose tolerances common.	4. Bridge components are prefabricated according to design specifications at a manufacturing plant.
5. All assembly of timbers takes place at bridge site.	5. Prefabricated, modern timber bridge components are integrated structural systems to facilitate quick installation.
6. Field construction and techniques do not allow best utilization of timber strength and performance.	6. Engineered premanufactured components increase the utilization of structural timber strength properties.
7. Maintenance often occurred only when problems became apparent.	7. An established inspection and maintenance program is administered.

Figure 3. Modern Timber Bridge with a Dowel-Laminated, Longitudinal Deck

A dowel laminated, longitudinal timber deck consists of southern yellow pine timbers, or other wood species of timbers, fastened together by high strength, galvanized steel dowels. The dowels pass through under-sized holes which are drilled prior to preservative treatment. Timbers extend the entire length of the deck. Prefabricated panels are constructed and then assembled on site to make a finished bridge deck. This design is most appropriate for spans up to 30 feet (Ritter, 1990).

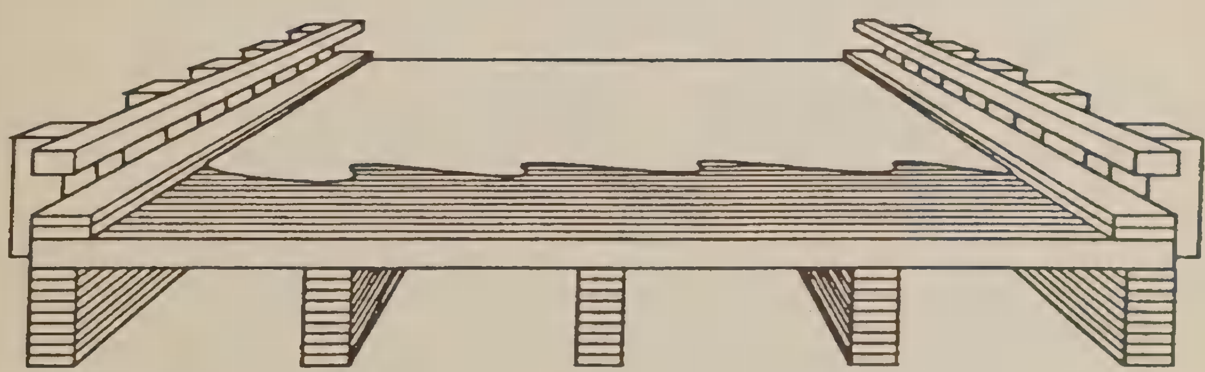


Figure 4. A Modern Timber Bridge With a Glulam Transverse Deck and Glulam Stringers

Glulam decks are constructed of Glulam panels, normally 5-1/8 to 8-3/4 inches thick by 3 to 5 feet wide, spanning the full width of the bridge. Glulam panels and stringers are fabricated from stressed-graded, southern yellow pine lumber laminated together with exterior adhesive. This design may include either steel or wood diaphragm bracing between stringers. It can be used for clear spans in excess of 100 feet. Estimated service life is 50 years or more (Ritter, 1990).

With modern timber bridge components appearing today, interest is renewed in timber as a structural material for framing and supporting massive constructed facilities. Several fundamental driving forces are working together to support the use of structural timber in bridge construction. The most prominent among these is the integral use of engineered, pre-manufactured timber components in transportation structures, such as culverts and bridges. The industrial production of these components has also led to enhanced strength standards, superior quality and treatment control, fast delivery and easy transportation to site, quick installation, and the use of light machinery for erection.

Minimum professional supervisory personnel are required for erection. These cost-effective measures are associated with the use of modern timber bridge components. This viable alternative construction method utilizing timber is expected to continue to grow. Research and development of modern timber bridges is continuing, and the concept of utilizing modern timber bridge components is spreading throughout the United States.

The limited number of prefabricated bridge components that have been used to date are proving to be cost competitive. With more applications and enhanced design innovations, these systems have the potential to create an advanced technologically based industry. Manufactured prefabricated, modern structural timber components, as an industry, are expected to expand before the turn of the century, especially in areas where industrial grade timber is available. The state of Mississippi is ideal for such an industry.

Advantages of Modern Timber Bridges

With recent technical advancements and the proven durability and longevity of modern timber bridges, they are a viable alternative for making rural bridge improvements. Some of their major advantages include:

Quick and easy to erect – avoids prolonged road closures and detours. Prefabricated modern timber bridge components are easy to handle and install by local work crews using equipment and tools owned by local jurisdictions. This results in labor cost savings. Lifting can be accomplished with smaller equipment since timber bridges are lighter in weight than most other bridge materials; 60 percent lighter than concrete (Ritter, 1990). In Alabama, after site preparation work was complete, a modern timber bridge 24 feet wide and 75 feet long was installed by local county crews within two working days. Their relatively lighter weight allows the opportunity for modern timber bridge components to be installed over existing substructure in rehabilitation projects (Nixon, unpublished).

Minimal maintenance – With state-of-the-art technology in wood preservative treating along with engineered structural designs, modern timber bridges reduce maintenance costs and prolong bridge life. Modern timber bridges are uniquely resilient to impact loads, earthquakes, tornados and other high winds, and are surprisingly fire resistant. Wood is not affected by deicing chemicals and freezing temperatures as are other bridge construction materials. Concrete road surfaces and bridges in areas of Mississippi where the temperatures frequently fall below 35 degrees Fahrenheit, relative to other areas of the state, have more rapid deterioration than elsewhere in the state (Ritter, 1990).

Environmentally compatible and aesthetically pleasing – Modern timber bridges are relatively simple to design and fabricate utilizing standard plans and national design standards. Each modern timber bridge can be designed to meet the needs of the job site using the American Association of State Highway and Transportation Officials (AASHTO) Specifications. No diverting of the stream is necessary, and limited substructure piling is required with clear spans well in excess of 60 feet readily available with modern timber bridges. Although timber bridges are especially ecologically well suited for rural wooded areas, they are versatile and adaptable to most settings (Ritter, 1990). Wood is Mississippi's number one natural renewable resource.

Mississippi's Forest Resources and Forest Products Industry

Mississippi's forests have been an important part of the state's economy for many years. In the 1840's, cords of fuelwood were cut and sold to power steamboats on the Mississippi River, and the 1920's saw the peak years of lumber production in the state as the virgin forests were cleared. Today, however, our forests are still important to our state economy and have been gaining in importance in the last two decades.

Forest products are also an important part of Mississippi's economy today, especially in rural communities. The forest products industry is Mississippi's leading agricultural sector with an estimated value of $972 million in 1993 at the first point of processing only. In 1992, forest products were the second most valuable agricultural commodity in Mississippi, behind cotton. But forest products ranked as the highest-valued agricultural commodity in 42 counties and were among the top three valued agricultural crops in 68 counties in 1992. Forestry's economic impact is distributed throughout most of the state. Forest products have been among the three highest-valued agricultural commodities at the first point of processing in Mississippi since the late 1970's.

Mississippi is a leading producer of forest products in the United States. The state has a modern, diversified forest products industry that manufactures dimension pine lumber, hardwood lumber, furniture, frames, treated lumber, poles, timbers, railroad ties, chips, composite panels like plywood, fiberboard and OSB, pulp, paper, and many other products. These manufacturing facilities are distributed throughout the state and form an important part of local economies.

Mississippi's forest products industry is a major manufacturing employer. Forest products firms provide nearly one in every four manufacturing jobs in the state. A list of the five largest employers in Mississippi includes three forest products companies. Forest products firms employed about 61,000 Mississippians in 1991. About 23 percent of these are employed in the lumber, plywood, and other wood products sector of the economy and are responsible for about 37 percent of the industry's value-added production. The forest products industry accounted for $1.8 billion in value-added production in 1986, which represented about 21 percent of all value-added by Mississippi manufacturers in that year.

Mississippi has about 17 million acres of commercial forest land consisting of both pine and hardwood forests. According to the Forest Statistics for Mississippi Counties-1987 by the U.S. Forest Service, pine forest types comprise about 28 percent of our forest acres, and oak-pine types occupy another 20 percent of the acreage. The remainder is in hardwood forest, primarily the oak-hickory type.

When timber volume is considered, pine accounts for 42 percent of the total, and hardwood species comprise 58 percent. These forests are owned mostly by private, nonindustrial landowners. Southern pine is an important component of Mississippi's forests. Even though pine forests by volume and acreage account for less than 50 percent of the state's forest resources, pine products, in 1992, accounted for 70 percent of Mississippi's harvest value. All totaled, pine products accounted for $571 million of the total timber harvest value of $810 million in 1992.

The southern U.S. is and will continued to be a major wood-producing region for the nation. The future of forestry in Mississippi looks very bright for the foreseeable future. Modern timber bridge components made from southern pine or other species can enhance Mississippi's forest products manufacturing sector while helping to repair the needed infrastructure for commerce and economic development.

Designation of Standard Highway Loading

All modern timber bridges discussed in this report are classified as HS 20-44. All State Aid or federally funded bridge projects must meet HS 20 specifications. However, county- and city-funded bridge projects may be less restrictive, and H 15 or H 20 bridge specifications may be used based on need and economics. For descriptive purposes, the following information was quoted from Standard Specifications for Highway Bridges, AASHTO, 1992:

"Minimum Loading –

Bridges supporting Interstate highways, or other highways, which carry heavy truck traffic shall be designed for HS 20-44 loading..."

"H Loading –

The H loadings consists of a two-axle truck or the corresponding lane loading. The H loadings are designated H followed by a number indicating the gross weight in tons of the standard truck."

"HS Loading –

The HS loadings consist of a tractor truck with semi-trailer or the corresponding lane load. The HS loadings are designated by the letters HS followed by a number indicating the gross weight in tons of the tractor truck."

"Affixing the Year –

Identifies the publication year*"*

Thus, bridges classified as HS 20-44 are designed for tractor trailer loading while bridges classified as H 20-44 are designed for standard truck loading without a trailer. As expected, the tractor trailer loading bridges, HS 20-44, require increased load capacity compared to standard truck loading bridges, H 20-44. For example, as bridge span length increases from 19 to 31 feet, there is a 38 percent increase in end shear loading, and a 16 percent increase in the design moment.

This means that for heavily loaded tractor trailers (e.g., log trucks), bridges classified as H 20-44 become increasingly less safe to cross as the bridge span length increases beyond 19 feet. Also, it would be reasonable to expect a shorter service life for a bridge classified as H 20-44 that is continuously being overloaded with tractor trailers.

Economic Analysis of Manufacturing Prefabricated, Modern Timber Bridge Components in Mississippi

Although there are many different types of modern timber bridge designs as listed earlier, and many others being researched and developed, two designs were chosen for this economic analysis of manufacturing prefabricated, modern timber bridge components in Mississippi. A dowel laminated, longitudinal deck design (Figure 3) was selected for bridge lengths from 18 to 28 feet. A Glulam transverse deck design with Glulam stringers was selected for longer bridge lengths from 30 to 50 feet (Figure 4). These were selected because they are included in the Standard Specifications of Highway Bridges published by the American Association of State Highway and Transportation Officials (AASHTO), and they are currently available on the market. Some of the other modern timber bridge designs mentioned in this report are in various stages of testing and approval by AASHTO.

Although the potential market for these two bridge types exists outside of Mississippi and the United States, Mississippi's bridge needs are concentrated in the short to intermediate lengths. The selected modern timber bridge designs for this study have a proven durability and longevity, and they are a viable alternative for rural bridge improvements in many states. Like all modern timber bridge designs, these two provide a means for a simple, lightweight, and quick bridge replacement.

Specifications for the two modern timber bridge designs were that all deck materials would use southern yellow pine, would be treated with creosote at a rate of 12 pounds per cubic foot, and would be designed for a minimum loading of HS 20-44. An HS 20-44 loading is designed to carry a tractor trailer truck with the allowable 80,000-pound load.

Modern Timber Bridge Cost Estimates

Although Mississippi has many sawmills and treating facilities that are needed to manufacture prefabricated, modern timber bridge components, the state does not have an existing facility to manufacture these components. To estimate the costs of producing the dowel laminated bridge components, 12 major Mississippi sawmills were sent engineering drawings of a representative bridge design and asked to submit their estimated cost of manufacturing the components. Estimates were solicited for bridges with lengths of 18, 20, 24 and 28 feet in length and 26 feet wide (two-lane bridge) with guard rails. Cost estimates on southern yellow pine timber, wood preservative treatment, and labor were solicited. When asked by phone and letter, 12 Mississippi sawmill managers said they would estimate costs, but only two mill managers actually responded, stating a lack of experience with the proposed modern timber bridge industry. Several others expressed interest in the proposed industry, but did not provide cost estimates.

To estimate the costs of producing the Glulam bridges for the longer lengths, engineering drawings of the design were sent to three companies. One company is located in Mississippi, one in Alabama, and one in Arkansas. The Mississippi company only produces Glulam structural members and was not able to estimate complete material, treating, and fabrication costs for the modern timber bridge design. The out-of-state companies have been in the Glulam modern timber bridge fabrication business for many years and submitted cost estimates for Glulam bridges of 30, 40, and 50 feet in length.

Cost Analysis

Guard railing costs were not included in any of the modern timber bridge estimates. It is usually suggested that galvanized metal guard rails be used because of their availability and cost. It also must be noted that wood has the highest strength-to-weight ratio compared to other construction materials normally used in bridge construction. Thus, the required substructure for modern timber bridges would be expected to be relatively less costly compared to other bridge types (Ritter, 1990; Peck et al, 1959). This cost savings in construction materials and labor were not included in this cost analysis because it is related to the soil-supporting characteristics of the bridge site.

Average, estimated costs for the prefabricated, dowel laminated modern timber bridge deck components, f.o.b. plant, are $17.25, $17.94, $22.21, and $33.42 per square foot of road surface for the 18-, 20-, 24-, and 28-foot single-span bridges, respectively. These costs include the required two supporting abutment caps for each bridge. The data are illustrated in Figure 5. As shown in Figure 5, the dowel laminated costs increase exponentially with increasing span length reflecting the higher costs for the longer, single piece timbers as the bridge increases in length.

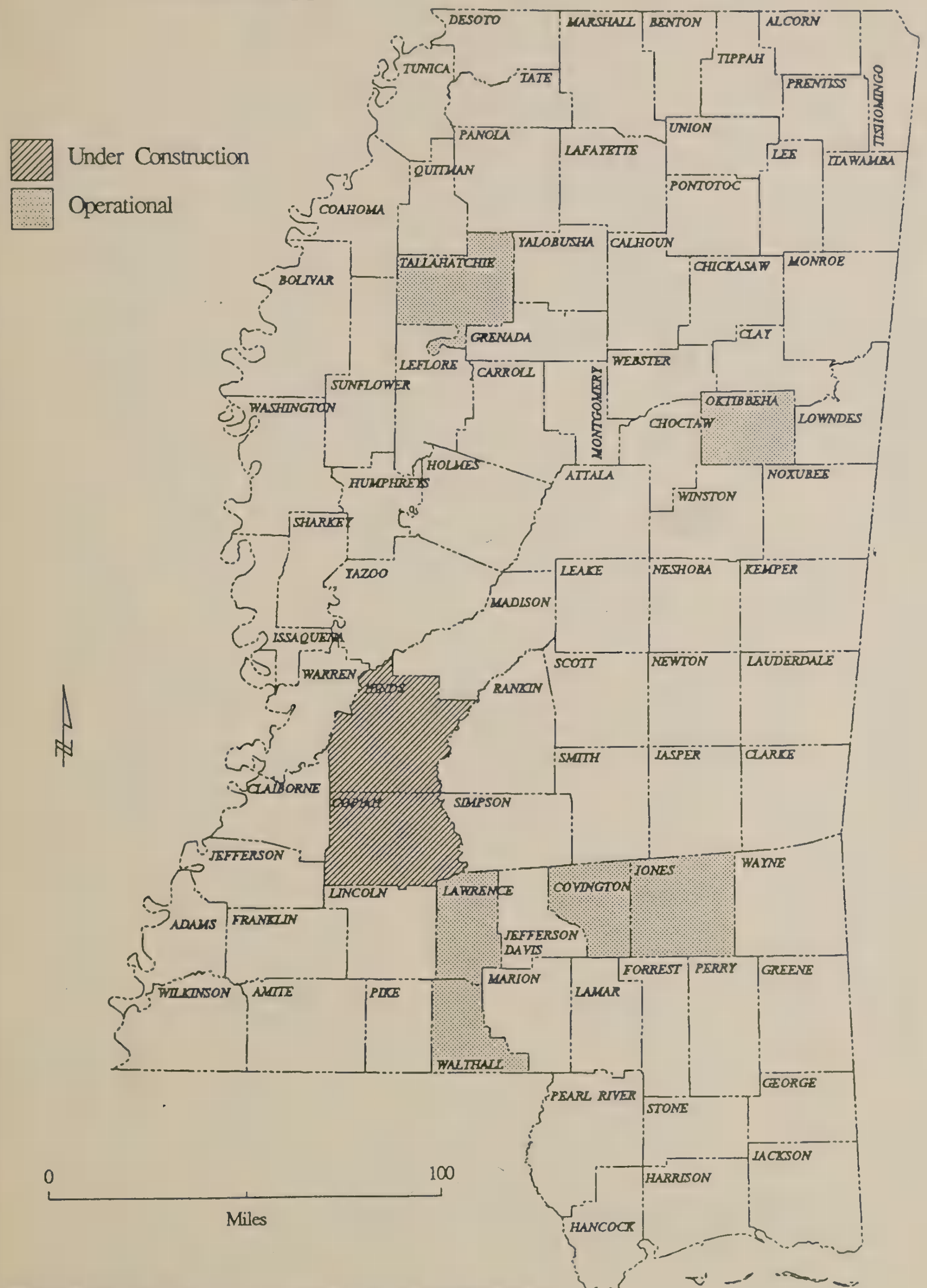
It should be noted that these estimated costs for in-state manufacturing of modern timber bridge components contain uncertainty and unfamiliarity factors. This is because the firm managers that estimated these costs are currently not producing the components. As firms are motivated to begin to build these bridges, and engineers are challenged to research designs and manufacturing techniques, the costs are expected to be lower then those reported here.

Average, estimated costs for the prefabricated, Glulam modern timber bridge deck components, f.o.b. plant, are $29.28, $32.12 and $34.69 per square foot of road surface for the 30-, 40- and 50-foot bridges, respectively. The data are illustrated in Figure 5. As shown in Figure 5, the per square foot bridge costs for the Glulam bridges increases gradually with increasing bridge length.

Currently, Mississippi has eight modern timber bridges in service on our rural highway system. The latest site is located in Hinds County. Map 3 shows the locations for these bridges. All of these demonstration modern timber bridges were built with special funds. No modern timber bridges have been built in Mississippi using Office of State Aid Road Construction funds.

During the last three years, southern yellow pine lumber has greatly increased in price. As an example, 2-inch by 10-inch by 12-foot long southern yellow pine framing lumber prices have increased from $252 per thousand board feet (MBF), kiln dried, f.o.b. mill, to $498 per MBF. That represents a 98 percent price increase. This price increase is illustrated in Figure 6. Obviously, this raw material price increase has a tremendous effect on total costs of modern timber bridge components fabricated from southern yellow pine.

Map 3. Locations of Modern Timber Bridge Demonstration Projects in Mississippi.



COOPERATIVE EXTENSION SERVICE

This map prepared by Extension GIS, Mississippi State University - Cooperative Extension Service. Extension GIS does not warrant its accuracy or completeness. Map prepared January 1994.

Figure 5. Estimated Costs For Mfg.
HS 20-44 Modern Timber Bridge Components
In Mississippi, Dollars/Square Foot.

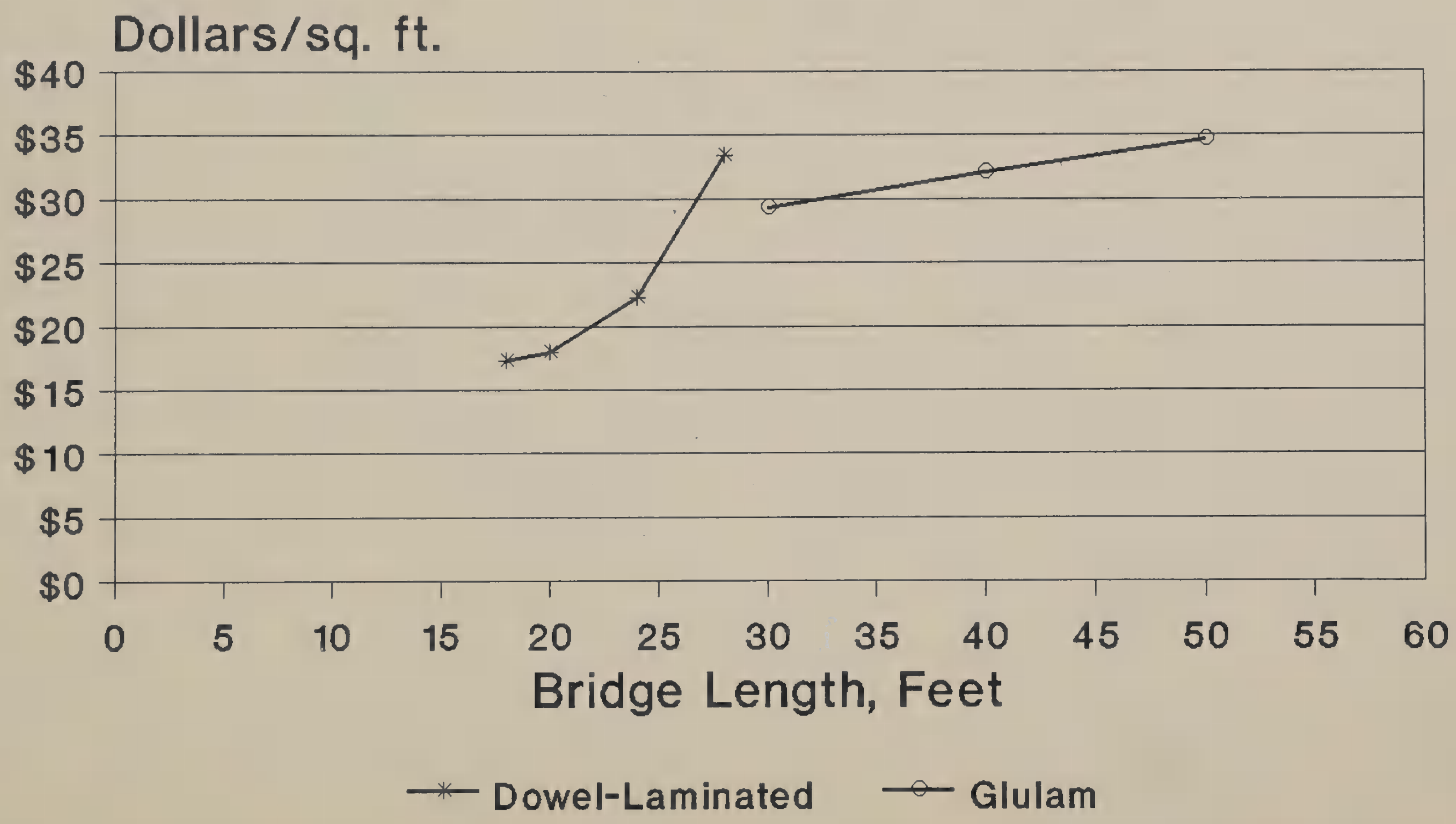
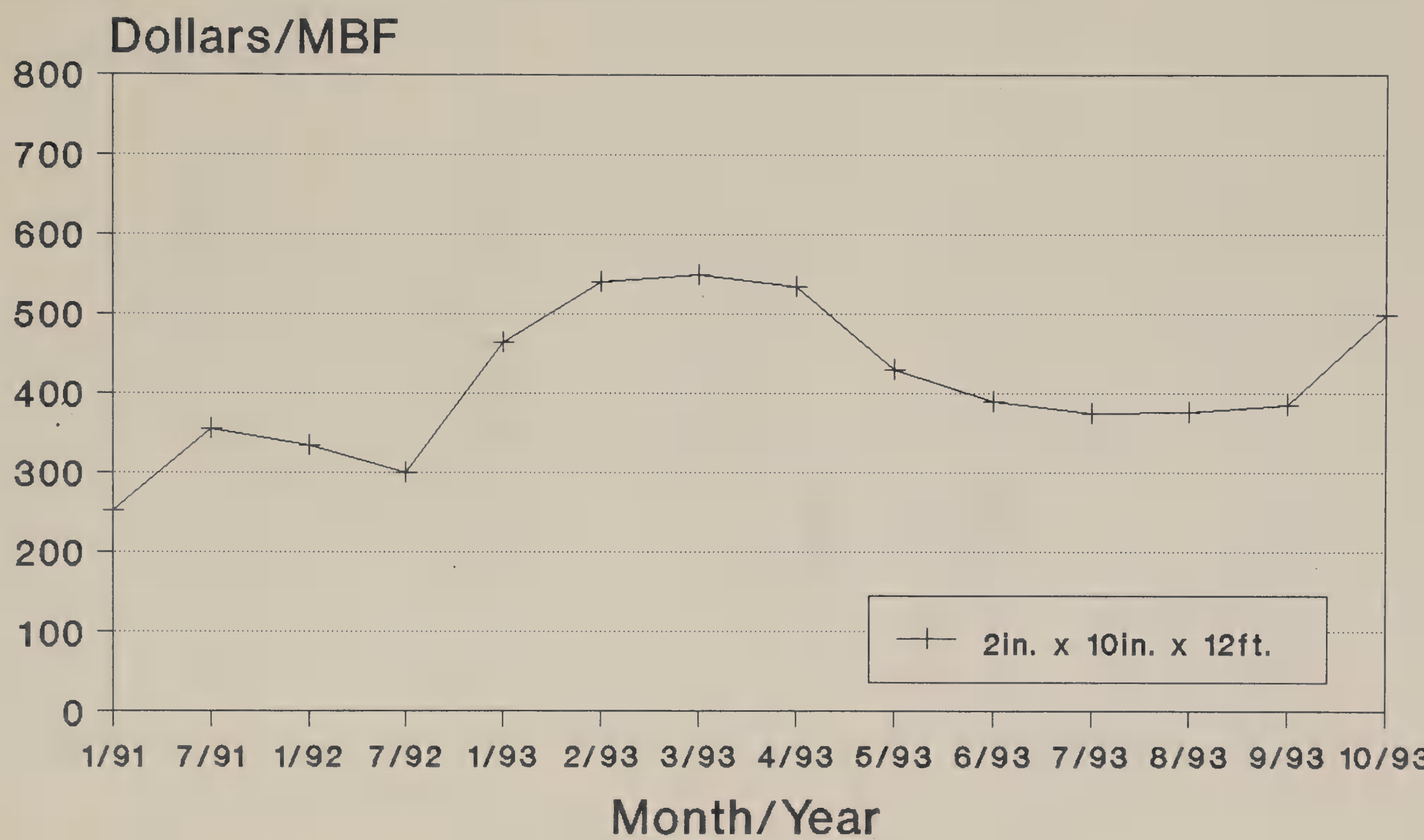


Figure 6. Framing Lumber Prices, Net F.O.B. Mill, For Southern Yellow Pine, Kiln Dried, Dollars/MBF.



Investment and operating costs for a proposed prefabricated, modern timber bridge component manufacturing plant would need to be determined on an individual basis because of the many different manufacturing possibilities that exist.

As an example, an estimated investment cost for buildings and equipment and associated operating costs for a simulated dowel laminated, modern timber bridge manufacturing facility producing 25-foot long and 26-foot wide components is given in Appendix A. This simulated manufacturing plant would purchase kiln dried, southern yellow pine timbers from a local sawmill and perform all the necessary cutting and drilling of the timbers prior to shipping the processed timbers to a local treating plant for treatment with creosote. The treated timbers would be shipped back to the manufacturing facility to be further processed into prefabricated, modern timber bridge components. Costs for five different annual output capacities were estimated. As output increased from 120 to 200 bridges annually, the production cost per square foot decreased from $25.00 to $18.00, respectively (Figure 7). Assumptions used in developing the model are included in Appendix A.

Cost and Economic Considerations

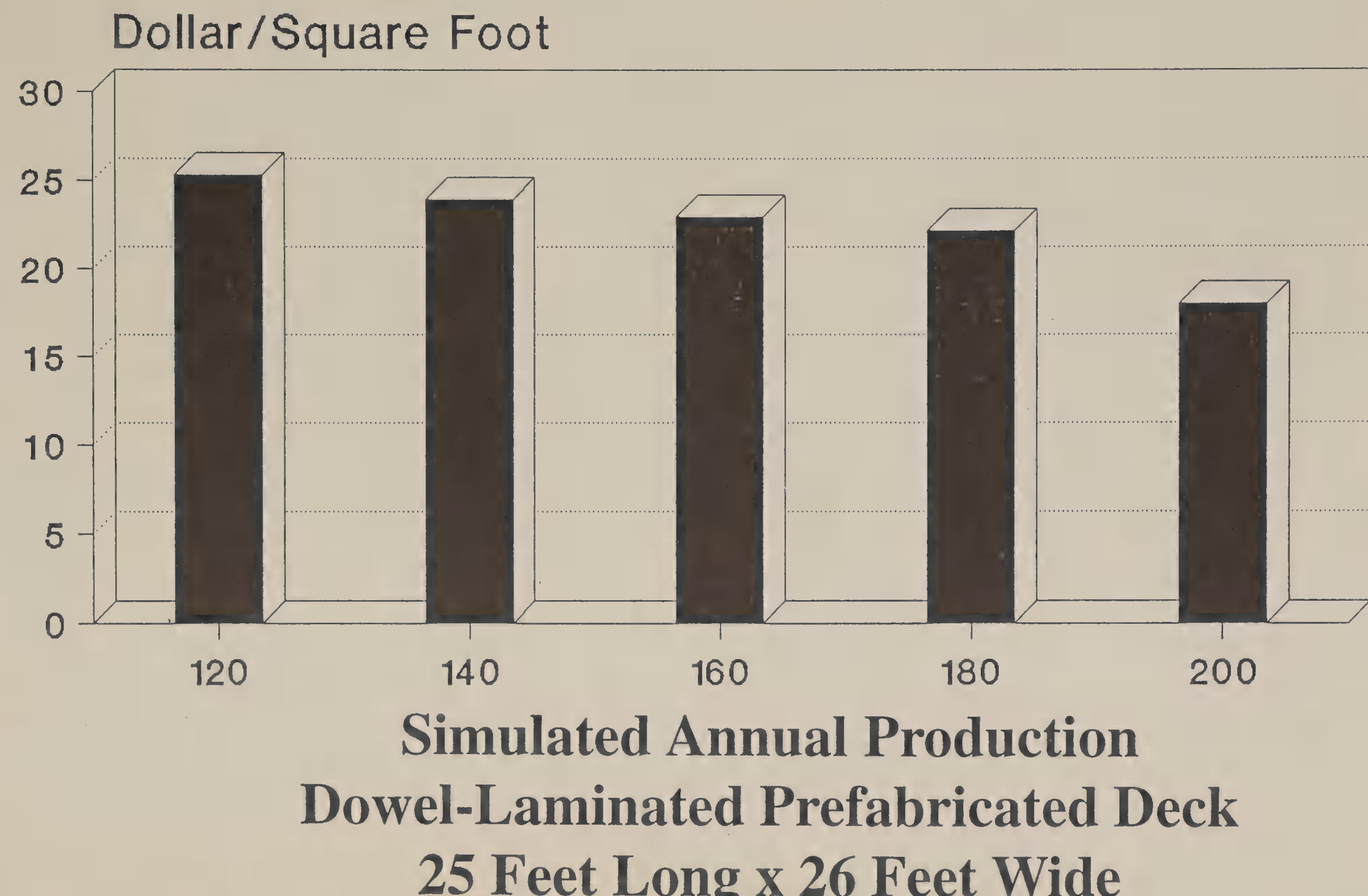
A discussion of the cost estimates of modern timber bridge deck components and of concrete bridge deck components is provided in Appendix B. This cost information was obtained from firms interested in producing modern timber bridge components in addition to firms which are actually producing such components. The cost data for concrete deck systems were obtained from a manufacturer of pre-cast concrete deck spans and from actual bridge installation costs as provided by the Mississippi State Aid Road Department. A discussion is also provided in Appendix B relating to the economic impact comparisons of a modern timber bridge deck industry and the concrete bridge deck industry on the state's economy.

Impact of Producing Modern Timber Bridge Components on the Timber Industry

The industrial production of modern timber bridge components will have a significant impact on the timber industry. The influence of this event can be explained by noting the experiences of the two other major structural materials in the construction industry – steel and concrete.

The steel industry has created the cold-formed metal building manufacturing system. The metal building industry is an engineered, premanufactured framing system using all steel metal products in the construction of the structural framing and the enclosures. This industry is capturing, at the present time, the lion's share of all single-story industrial buildings and similar single-story structures such as churches, athletic facilities, and schools. The metal building industry is advancing, at the present time, into the commercial and private housing markets. In a period of only 20 years, it has now become a United States trade mark, capturing over 50 percent of all single-story industrial buildings nationwide.

Figure 7. Estimated Cost For Simulated Mfg. of Prefabricated, Modern Timber Bridge Components, Dollar/Square Foot.



The production of pre-engineered metal framed buildings has been growing at a phenomenal rate every year for the past ten years. The metal building system is presently flourishing all over the United States, and it is spreading now overseas into the civilized industrial world.

The concrete industry offers precast and prestressed concrete products. This industry produces engineered precast units of either prestressed or regularly reinforced concrete. Prestressing steel cables or common reinforcing steel bars are used for reinforcement. The pre-engineered precast reinforced units and prestressed concrete bridge beams have captured and dominated the market for short- to medium-span highway bridges. The precast and prestressed concrete industry is moving ahead to dominate the single- and low-rise building construction industry, leaving behind the traditional cast-in-place concrete framing systems.

Today, reinforced concrete as a construction material is the most commonly used structural material for bridge decks and bridge beams for the construction of highway bridges on primary roads. Precast prestressed concrete bridge beams are now proven to be cost effective and are used almost exclusively for major overpasses of medium-span length. The industry for producing and manufacturing prestressed concrete bridge beams has spread nationwide. The system has been optimized structurally and manufactured to standard sizes and shapes for efficient industrial plant production programs. The final product as it is today is easy to produce, easy to transport, quick to install, and very efficient to utilize in construction. The major draw-back is its bulkiness and, therefore, it is extremely heavy in weight.

Timber is a relatively light structural material. The trend in utilizing modern prefabricated, treated timber bridge components can be found in the natural application of the experiences of similar technological advances of steel and concrete during the past two decades. Engineers and foresters are working together today to reestablish this structural material in the bridge construction industry. Timber as a structural material is going to take its modern form reflecting new and innovative designs and technologies of the past decade.

Modern timber bridges require little or minimum maintenance over the years and with bituminous mat cover (asphalt) over the wooden deck, the bridge wearing surface will match in appearance the same finish as the roadway itself. Repairs on timber bridges can be made within days, if not hours, of interruption of traffic and can be made with minimum demands for highly qualified engineers and professionals. For construction, repair, and maintenance of rural modern timber bridges, only light- to medium-size construction equipment and hand tools are required (Ritter, 1990).

The proposed industry for premanufacturing modern timber bridge components will be expected to provide at the same time structural elements for other applications in transportation and construction. It should also be noted that the new methods for assembling prefabricated, modern timber components are already spreading into the other traditional timber construction markets. Today, prefabricated timber trusses or joists, and pre-assembled panels or partition units, are finding direct applications in the housing construction industry. Other structural applications for pre-manufactured, pre-engineered bridge components are also found in almost all constructed facilities where timber is a viable alternative as a construction material. The manufacturing industry for prefabricated, modern timber bridge components may also assemble other structural materials for use in building systems and other construction needs, such as beams, girders and stringers, joists, trusses, decks, pilings, pile caps, sheet pilings, abutments, culverts, load spreaders, footings, and noise barriers.

Road Surface Requirements for Modern Timber Bridges

Asphalt-wearing surfaces are commonly used with modern timber bridge decks. The thickness of the wearing surface is usually 3 to 4 inches. The asphaltic wearing surface has the advantage of creating continuity of the appearance with the riding finished surface of the roadways leading to the bridge. However, it is possible to eliminate the asphalt wearing surface completely when using modern timber bridges. The surface of the finished timber deck in modern timber bridges has a tight, smooth riding surface that might be suitable to use for bridges with very low and slow traffic volume on a secondary rural road. This measure is usually not desirable, but when taken, it is strictly made for cost-saving purposes.

The asphaltic wearing surface requires very special attention and consideration in modern timber bridges because of the mis-match in the engineering properties between asphaltic mixes and the timber deck itself. Several minor problems have been noted to occur as a result of this mis-match, especially over a long period of time after construction.

The most common problem is related to the differences in the flexibilities between the asphaltic overlay and the timber deck. This causes the asphaltic overlay to bleed and collect in an uneven fashion, causing a noticeable roughness to the riding surface. Another possible problem is related to surface separation between the asphaltic overlay and the finished surface of the timber deck. The surface separation could lead to breaking up of the asphaltic overlay, and possibly losing part of it, causing a rough finish to the riding surface. This failure of the wearing surface is very similar to commonly experienced shallow pot holes in road surfaces. Several measures are available today to guard against or minimize the occurrence of these undesirable features. Additional research and development of new methods, such as additives to the asphaltic concrete overlay, is needed to satisfactorily solve this problem.

Specifications

The current specifications on placing asphaltic-wearing surface on modern timber bridge decks usually include use as a surface blotter material to absorb any excess timber preservative before applying an emulsified asphaltic tack coat to the timber bridge deck. The surface blotter material is usually made up of a uniformly graded mixture of dust (silt, sandy silt, or other friable soils) and 10 to 20 percent crushed fine material passing a No. 8 sieve. The blotter material is spread at a rate of 10 to 15 pounds per square yard of bridge deck surface. Immediately after spreading the blotter material, a rubber-tired roller is used to increase its effectiveness in absorbing excess preservative.

After the excess preservative has been absorbed, the blotter material is removed by brooming, so the deck surface is thoroughly cleaned of all dirt and debris. The surface is then coated with the asphalt tack coat to be followed by placing the commonly used 3- to 4-inch thick asphaltic concrete overlay. The mixing of the asphaltic overlay is the same as that commonly used for roadway works, and the finished surface is, therefore, the same.

Current research is investigating the merits of using geotextiles as a membrane reinforcement to the asphaltic overlay and as a waterproofing and stress relieving membrane. Also, asphaltic concrete using blended hydraulic cements with slag or pozzolan, or both, is also being considered.

Maintenance and Repair

Asphaltic overlays placed on top of modern timber bridge decks require regular inspection for proper maintenance and needed repairs. The life span of the presently used overlays is from 5 to 8 years.

A new overlay can easily be placed after scraping off the old overlay. Depending on the width of the bridge roadway, it could be done in a matter of days without interruption of traffic or loss of effective use of the bridge. The cost of placing asphaltic-wearing surface on a timber bridge deck varies from between $.80 and $1.20 per square foot, depending on the size of the bridge, location, and vicinity of similar roadway work being done at the time the overlay is placed on the bridge deck.

Southern Yellow Pine and Its Treatment

Southern yellow pine (SYP) is an ideal material for use in modern timber bridges in Mississippi. Not only does southern pine wood have favorable strength characteristics (Summitt & Aliker; Koch, 1972), but the large body of information that exists about its anatomy, physical and mechanical properties, machining and gluing characteristics, and treatability (Koch, 1972a; Koch, 1972b), permits engineers to design and construct bridges for use in a variety of settings. In addition, the number 2 or better grades of wood that are needed for constructing timber bridges are available in sufficient quantities to support a timber bridge manufacturing industry. Only properly graded and stamped kiln-dried lumber should be used when manufacturing bridge components.

Southern pine typically has a wide band of sapwood that is readily treated by a variety of wood preservative systems, but the heartwood treats very poorly (Koch, 1972b). For this reason, wood for use in bridge components should be chosen by both grade (number 2 and better) and sapwood content. To be on the safe side, all heartwood faces on either laminated or solid bridge components should be oriented so they are not directly exposed to the weather. Also, all machining and drilling of bridge components should be done prior to treatment. The surfaces of all cuts made at the construction site should be brush-treated with preservative.

The preservative of choice for treating southern pine bridge components is clean coal tar creosote that conforms to the American Wood-Preservers' Association (AWPA) standard P1/P13, and the "creosote in use" should not exceed 0.5 percent xylene insolubles (xi). Bridge components should be treated to an assay retention of 12 pounds per cubic foot (pcf) in the assay zone according to procedures given in AWPA standards C1, C2, and C14 for solid lumber and timbers; AWPA standards C1, C14, and C28 for laminated components; and AWPA standards C1 and C3 for piling (Table 4).

TABLE 4. American Wood-Preservers' Association Standards[a] that are Applicable to the Treatment of Timber Bridge Components.

Standard Number	Title
P1/P13[b]	Standard for coal tar creosote for land and fresh water and marine (coastal water) use.
C1	All timber products--preservative treatment by pressure processes.
C2	Lumber, timbers, bridge ties, and mine ties--preservative treatment by pressure processes.
C3[c]	Piles--preservative treatment by pressure processes.
C4	Wood for highway construction-preservative treatment by pressure processes.
C28	Standard for preservative treatment of structural glue laminated members and laminations before gluing of southern pine, Pacific Coast Douglas fir, hemfir, and western hemlock by pressure processes.
M2	Standard for inspection of treated timber products.

a Standards as published in the latest edition of the American Wood–Preservers' Association Book of Standards, P.O. Box 286, Woodstock, MD 21163-0856.

b In addition to the requirements given in standard P1/P13, the "creosote in use" should not exceed 0.5% xylene insolubles (xi).

c The white-wood used for piles should conform to the current American National Standards Institute (ANSI) Standard dealing with wood piles. In addition to the requirements given in AWPA Standard C3, all piles from every charge should be bored and inspected for conformance to penetration requirements given in standard C3.

Treated materials should be inspected and stamped at the treating plant by an independent inspection agency for adherence to standard and supplemental specifications given in the AWPA standards and written instructions provided by the buyer. Inspections should be performed as specified in AWPA standard M2. To assure clean, drip-free creosote-treated stock, the procedures given in the AWPA standards previously referenced should be supplemented using procedures given by Baileys (Baileys, 1994) for producing clean creosote-treated southern pine poles. These include: (1) use the minimum initial air required to achieve a 12 pcf assay retention; (2) condition kiln-dried materials that have been treated by using expansion bath techniques; and (3) use an alternating vacuum and streaming cycle following treatment for a minimum of five to six hours. During the after-treatment inspection, material that is bleeding creosote and/or has excessive surface deposits of treating solution components or debris should not be accepted. A further discussion of treatment processes and procedures is given in the USDA Forest Service timber bridge manual (Ritter, 1990).

Although some concern has been expressed about environmental contamination caused by using creosote-treated wood in watersheds, evidence indicates that this is not a problem (Freeman, 1990; Webb and Gjovik, 1988; Webb, 1975). Neither soil nor water adjacent to creosote-treated wooden structures has been contaminated as long as care was taken to avoid excessive bleeding of creosote by altering the treatment process as outlined above.

Inspection and Maintenance of Timber Bridges

No structure should be built without provisions for periodic inspection and maintenance, and timber bridges are no exception. Field personnel need to be trained to make periodic inspections and to determine maintenance needs (Amburgey, unpublished).

While detailed discussions of timber bridge inspection techniques and maintenance procedures are given elsewhere (Ritter, 1990), it should be emphasized here that inspections should concentrate on areas where deterioration problems are likely to occur. For instance, deterioration of wooden support piles would likely result from exposure of untreated heartwood and water penetration around the bolt holes at joints or from gradual depletion of preservative near groundline. Bolts should periodically be inspected for tightness and corrosion or signs of water penetration into the wood adjacent to them. Either liquid or paste-type preservative formulations should periodically be applied to these areas. Depletion of preservative at the groundline of piles can be compensated for by periodically applying groundline preservative treatments or injecting fumigants as is now commonly done with utility poles.

In a survey of rural bridges in Oktibbeha County, many bridge support piles were decaying near groundline while others remained sound after more than 25 years with no supplemental preservative treatments (Amburgey, et al, unpublished). Cores removed from inspected piles were assayed for creosote retention, and it was found that nearly all decayed piles had a retention of 5 pounds of creosote per cubic foot of wood or less. These results indicate that it is important to periodically assay treated wood components for retention of preservative. With creosote-treated southern pine bridges, any components found to have 5 pcf or less preservative should be replaced.

Bridge decks and support beams should be carefully inspected at all joints, especially those exposed to periodic wetting, to check for tightness and corrosion of bolts and deterioration of wood caused by water entering these areas. As with piles, liquid or paste-type preservative formulations should be applied to joints. Locations where wooden components were cut during construction should be inspected carefully, and any components in direct contact with soil should be checked for signs of subterranean termite activity. All checks and splits that face upward and collect water during rains should be filled with a paste-type formulation of a diffusible preservative (borates or fluorides) or flooded with a liquid preservative.

All bridges should be inspected by trained personnel on a regular basis (e.g., one to five years). If one-fifth of the bridges in a county were inspected every year, no bridge would go without an inspection for more than five years.

Disseminating Project Results

The modern timber bridge team makes the following recommendations for the dissemination of the project findings:

1. A packet of information be prepared on project findings and provided to appropriate local government officials – mayors, city clerks, city engineers or consulting city engineers, public works directors, etc. on the municipal side and supervisors, county engineers, county administrators, county board attorneys, chancery clerks, etc. on the county side.

2. Explore the possibilities of building an exhibit booth displaying project information to be used at major conferences and conventions of selected local government associations such as:

   A. Annual Conference of the Mississippi City/County Management Association.
   B. Joint Education Workshop for the Mississippi Chancery Clerks Association and the Mississippi Association of County Administrators/Comptrollers.
   C. Annual Conference of the Mississippi Municipal Association.
   D. Annual Convention of the Mississippi Association of Supervisors, which includes meetings of the Mississippi Association of County Board Attorneys, the Mississippi Association of County Engineers, and the Mississippi Association of County Administrators and Comptrollers.

3. A presentation be made by the appropriate individual or individuals on the project findings at the educational program presented as part of the meetings of local government officials listed previously in Number 2.

4. Meetings be established by the appropriate forestry or wood products groups with the appropriate officials of the appropriate state entities (Mississippi Department of Economic and Community Development, Mississippi Department of Transportation, Office of the Governor, the Legislature, etc.) to disseminate project findings.

5. The private or public sector organizations which might support the use of timber bridges as economic development (the Mississippi Department of Economic and Community Development, the major forestry and wood products groups, etc.) could arrange with the appropriate legislative committees the holding of hearings on the use of timber bridges as a construction technique and an economic development tool.

While the team members feel actual preparation and development of educational information and dissemination (delivery) is outside the functions of the committee, members of the project team will assist the further development of this project in any way.

Activities of Other States

Many states are developing timber bridge programs and adopting initiatives that suit their individual needs. Currently, Mississippi is not one of them. This section gives a short summary of the actions being taken by other states to incorporate modern timber bridge technology into their transportation systems.

Alabama. Standard design drawings for timber bridges have been established in the State Highway Department office in Montgomery.

Alaska. The University of Alaska, at Fairbanks, is testing methods to enhance the double diffusion process for white spruce. In connection with this research, the state is promoting the use of white spruce in timber bridges. Two tested processes have shown promise for improving treatment. In one procedure, the timbers are wrapped after immersion. This slows the drying process and allows the diffusion process to continue, which permits better penetration of chemicals. The second process tested uses ultrasonic waves to increase chemical penetration. When the success of these processes is verified, the results will be published.

Colorado and Louisiana. Engineering Data Management, of Colorado, in conjunction with the Louisiana Department of Transportation and Development, determined the length and soundness of piles by using stress wave propagation. The areas where piles wear most, from scour and/or rot, are readily identified in this process. A publication is available.

Iowa. This state is proceeding with the development of standard design plans for demonstration timber bridges built with cottonwood. The fabrication plans are near completion, along with a timber network to support manufacture and fabrication of timber bridges.

Kansas. In eastern Kansas, the Lake Region RC&D Council is installing two drop box spillway structures to reduce erosion. Emphasis is placed on using readily available timber from local merchants to build energy checking drop structures. They will use both CCA and creosote treated materials.

Maine. Maine recently passed a bill to fund a $700,000 timber bridge program. Research projects are designated to receive $300,000. The remaining $400,000 will be used for demonstration timber bridges.

Massachusetts. A $1,500,000 bond was passed to support a timber bridge program in Massachusetts. It will fund demonstration timber bridges in state forest and state park systems. This resulted from the efforts of the state legislature and the state forester's office. The chief forester in Massachusetts is Warren Archey.

The Massachusetts Division of Forests and Parks is involved in a marketing study to increase the acceptability of timber for short-span bridges and related rural road applications.

Michigan. The Huron Pines RC&D Council, Inc., is evaluating the potential for manufacturing and marketing modern timber bridges to aid Michigan's efforts to rebuild its transportation infrastructure.

New Hampshire. The North Country RC&D Area, Inc., is developing design standards for timber binwall retaining structures and evaluating the future market for sales of these products.

New York. The Greater Adirondack RC&D Council is developing plans and specifications for a timber binwall that will stabilize soils subject to erosion or movement. When completed, the plans will be standardized for the state department of transportation.

Allegheny County has its own timber bridge program for fabricating and installing timber bridges. The Timber Bridge Information Resource Center in Morgantown, West Virginia, will document their operation with a case study.

Ohio. The Timber Bridge Information Resource Center is developing a case study to describe Ashtabula County's timber bridge program. Work there is accomplished by county crews, and the study will include resourceful ways the county has attempted to achieve optimum use of its materials and equipment. The county crews perform most of this program work during slack winter periods.

Oregon. Oregon's Department of Transportation with the Wood Products Center have an engineer skilled in timber design. They provide direct technical assistance and information on modern timber bridge designs, specifications, etc., to counties throughout the state.

Pennsylvania. The Pennsylvania Wood Industry Association is evaluating red maple as structural timber for bridges in the hardwood states, particularly in Pennsylvania. The study focuses on structural yield and costs for producing structural grade timber for bridges, taking into account development of the expertise needed.

Vermont. The Vermont Agency of Transportation, working with the VT Department of Forestry and RC&Ds, have designed a timber binwall that will allow most timber species native to Vermont to be used in binwall construction. A conference was held in March 1992 on design and use of timber binwalls, and a Timber Bridge Special Project grant has been approved for Vermont to build a demonstration timber retaining wall at Arlington, VT. This project, and information gained from it, should result in designs that will allow binwalls to be constructed nationwide from locally native timber species.

Virginia. Virginia is in the process of installing seven demonstration bridges. Two more demonstration bridges scheduled for next year will bring the total to nine.

The Center for Forest Products Marketing at Virginia Polytechnic Institute and State University is studying the tendency to adopt new timber bridge technology, its effect on the timber bridge market, and its effect on rural economic development. The study is intended to evaluate barriers to adoption, develop strategies to overcome these barriers, and to identify the most promising market segments.

West Virginia. The Construction Facilities Center of West Virginia University is developing a manual for designing and load rating modern stressed timber bridges, supporting modern timber bridge technology developed through the Timber Bridge Initiative. The manual will include a step-by-step design and load rating process that can be in field use with minimum training for inspectors.

Wisconsin. The Wisconsin Resource Conservation and Development Council is conducting a study to identify the potential market demand for timber bridges.

Closing Comments

Rural bridges adequate for the passage of heavy trucks are considered to be vitally important to Mississippi's agriculture and rural economy.

It has been shown that Mississippi's rural bridge needs are concentrated in the short to intermediate range. Over 50 percent of Mississippi's structurally deficient bridges are between 20 and 60 feet in length.

Simple, lightweight, and quickly constructed bridges and bridge components are a priority need and have some advantages in making needed bridge repairs. The thrust of the National Modern Timber Bridge Initiative is focused on these aspects. Recent efforts have concentrated on establishing and promoting the durability and longevity of modern timber bridges to ensure their consideration as a viable alternative for making rural bridge improvements. But, for Mississippi to take advantage of the opportunities that exist for a modern timber bridge manufacturing industry, several requirements are necessary:

- Allow modern timber bridges to compete for State Aid bridge improvement funds, to establish a data base on the use and performance of modern timber bridges in Mississippi, and to allow alternative solutions to present bridge construction methods.

- Position expertise on modern timber bridge construction within the Mississippi Department of Transportation and the Office of State Aid Road Construction.

- Adopt standard drawings with associated specifications for modern timber bridges within the Mississippi Department of Transportation and the Office of State Aid Road Construction.

- Allocate significant State Aid Road Construction/Mississippi Department of Transportation funds for modern timber bridge research, development and demonstration in Mississippi. Such funding will stimulate innovation in design and manufacturing of modern timber bridges in Mississippi to further develop our state's information base on this bridge alternative.

Although Mississippi has the timber resource and necessary initial processing facilities, without these requirements being fulfilled, it would be extremely difficult to establish a prefabricated, modern timber bridge manufacturing industry in the state. In addition to Mississippi and U.S. markets, with the North American Free Trade Agreement (NAFTA) in effect, Mississippi is ideally located to capitalize on the market opportunities for modern timber bridges in Mexico.

Photo by Linda Breazeale

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Appendix A

Estimated Investment and Operating Costs for a Simulated Manufacturing Facility Producing HS 20-44, Dowel Laminated, Prefabricated, Modern Timber Bridge Components

Model Assumptions

The following assumptions were used to estimate the investment and operating costs for a simulated manufacturing facility producing HS 20-44, dowel laminated, prefabricated, modern timber bridge components in Mississippi:

1. Plant output based on 240 working days with one eight-hour shift per day.
2. Plant output based on prefabricating an average-size bridge of 25 feet long and 26 feet wide.
3. Raw lumber purchases were estimated to be $800 per MBF of kiln dried southern yellow pine delivered.
4. Purchases include $300 per bridge for hardware.
5. Preservative treatment was estimated to cost $300 per MBF of lumber.
6. Wages and salaries were estimated using wood products industry averages for Mississippi.
7. Operating costs were estimated using similar wood products manufacturing operations as a guide.
8. Depreciation was calculated using the straight-line method, no salvage value, 30 and 10 years life for buildings and equipment, respectively.
9. Interest on operating capital was estimated to be 8.75 percent annually and on long-term debt to be 7.5 percent.
10. Equipment costs were estimated from information collected from existing timber bridge manufacturers in other states and wood products industry sources.
11. This model does not take into consideration any transportation costs.
12. A sensitivity of changes in output from 200 to 120 bridges per year was performed to determine the effect of profitability.
13. The assumed selling price was $25/square foot.

Estimated Capital Investment for Dowel Laminated Modern Timber Bridge Fabrication Plant, Mississippi 1994

Land 5 acres @ $1,000 per acre	$5,000
Fabrication Building, 250' x 200' @ $21.00 sq.ft.	$1,050,000
Raw material Storage, 100' x 100' @ $12.00 sq.ft.	$120,000

Total buildings	$1,170,000
Equipment:	
2 Heavy duty forklifts @ $30000 each	$60,000
2 Assembly Tables @ $40,000 each *	$80,000
2 Heavy Duty Boring machines @ $35,000 each	$70,000
1 Cut-off Saw @ $40,000 *	$40,000
3 Heavy Duty Overhead cranes w/rail system @ $25,000 ea.	$75,000
1 Machine Shop w/supplies @ $78,000	$78,000

Total equipment	$403,000
* Custom fabrication of this equipment is half the cost of initial investment	
Total Capital Investment	$1,578,000
Less 20% down payment	$315,600

Balance of investment	$1,262,400
Working Capital Requirements	$458,640

Principal amount to be financed	$1,721,040

Employment Schedule

Position	Number required	Hourly Wage Rate
Forklift Operater	2	$9
Maintenance	2	$17
Maintenance Helper	1	$12
Shift Workers	15	$7
		Salary
Manager	1	$55,000
Secretary/bookkeeper	2	$14,000
Engineer	1	$50,000
Sales/purchasing	1	$40,000

Simulated Dowel Laminated Modern Timber Bridge Fabrication Plant
Mississippi 1994, Output 200 (25' x 26')Bridges per Year
Operating Statement

Sales		$3,250,000	100%
Cost of Goods			
Purchases	$1,308,000		40%
Direct labor	$236,160		7%
Treatment	$468,000		14%

Cost of Goods Sold		$2,012,160	62%

Gross Profit		$1,237,840	38%
Expenses			
Indirect Labor	$88,320		3%
Celerical	$28,000		1%
Salaries	$145,000		4%
Payroll taxes	$37,311		1%
Office supplies	$2,880		0%
Plant supplies	$97,500		3%
Benefits	$43,836		1%
Utilities	$130,000		4%
Phone	$4,200		0%
Insurance	$12,750		0%
Maintenance/Repair	$19,375		1%
Taxes	$16,897		1%

Operating expenses	$626,069		19%
Interest on operating expenses	$38,474		1%

Total operating expense		$664,543	20%

Operating profit		$573,297	18%
Other expenses			
Building Depreciation	$39,000		1%
Equipment Depreciation	$26,500		1%
Interest on long-term debt	$132,408		4%

Total other expenses		$197,908	6%

Net profit before Income Tax		$375,389	12%
		=======	

Cost per sq.ft. $18.02

Simulated Dowel Laminated Modern Timber Bridge Fabrication Plant
Mississippi 1994, Output 180 (25' x 26')Bridges per Year
Operating Statement

Sales		$2,925,000	100%
Cost of Goods			
Purchases	$1,177,200		40%
Direct labor	$236,160		8%
Treatment	$421,200		14%

Cost of Goods Sold		$1,834,560	63%

Gross Profit		$1,090,440	37%
Expenses			
Indirect Labor	$88,320		3%
Celerical	$28,000		1%
Salaries	$145,000		5%
Payroll taxes	$30,844		1%
Office supplies	$2,520		0%
Plant supplies	$87,750		3%
Benefits	$43,836		1%
Utilities	$117,000		4%
Phone	$3,000		0%
Insurance	$8,500		0%
Maintenance/Repair	$22,300		1%
Taxes	$16,897		1%

Operating expenses	$593,967		20%
Interest on operating expenses	$35,416		1%

Total operating expense		$629,383	22%

Operating profit		$461,057	16%
Other expenses			
Building Depreciation	$39,000		1%
Equipment Depreciation	$26,500		1%
Interest on long-term debt	$129,078		4%

Total other expenses		$194,578	7%

Net profit before Income Tax		$266,479	9%
		=======	

Cost per sq.ft. $22.16

Simulated Dowel Laminated Modern Timber Bridge Fabrication Plant
Mississippi 1994, Output 160 (25' x 26')Bridges per Year
Operating Statement

Sales		$2,600,000	100%
Cost of Goods			
Purchases	$1,046,400		40%
Direct labor	$236,160		9%
Treatment	$374,400		14%

Cost of Goods Sold		$1,656,960	64%

Gross Profit		$943,040	36%
Expenses			
Indirect Labor	$88,320		3%
Celerical	$28,000		1%
Salaries	$145,000		6%
Payroll taxes	$37,311		1%
Office supplies	$2,400		0%
Plant supplies	$78,000		3%
Benefits	$43,836		2%
Utilities	$104,000		4%
Phone	$3,000		0%
Insurance	$8,500		0%
Maintenance/Repair	$16,450		1%
Taxes	$16,897		1%

Operating expenses	$571,714		22%
Interest on operating expenses	$32,501		1%

Total operating expense		$604,215	23%

Operating profit		$338,825	13%
Other expenses			
Building Depreciation	$39,000		2%
Equipment Depreciation	$26,500		1%
Interest on long-term debt	$125,748		5%

Total other expenses		$191,248	7%

Net profit before Income Tax		$147,577	6%
		=======	

Cost per sq.ft. $22.95

Simulated Dowel Laminated Modern Timber Bridge Fabrication Plant
Mississippi 1994, Output 140 (25' x 26')Bridges per Year
Operating Statement

Sales		$2,275,000	100%
Cost of Goods			
Purchases	$915,600		40%
Direct labor	$236,160		10%
Treatment	$327,600		14%

Cost of Goods Sold		$1,479,360	65%

Gross Profit		$795,640	35%
Expenses			
Indirect Labor	$88,320		4%
Celerical	$28,000		1%
Salaries	$145,000		6%
Payroll taxes	$37,311		2%
Office supplies	$2,400		0%
Plant supplies	$68,250		3%
Benefits	$43,836		2%
Utilities	$91,000		4%
Phone	$2,640		0%
Insurance	$8,500		0%
Maintenance/Repair	$16,450		1%
Taxes	$16,897		1%

Operating expenses	$548,604		24%
Interest on operating expenses	$29,574		1%

Total operating expense		$578,178	25%

Operating profit		$217,462	10%
Other expenses			
Building Depreciation	$39,000		2%
Equipment Depreciation	$26,500		1%
Interest on long-term debt	$122,418		5%

Total other expenses		$187,918	8%

Net profit before Income Tax		$29,544	1%
		=======	

Cost per sq.ft. $23.96

Simulated Dowel Laminated Modern Timber Bridge Fabrication Plant
Mississippi 1994, Output 120 (25' x 26')Bridges per Year
Operating Statement

Sales		$1,950,000	100%
Cost of Goods			
Purchases	$784,800		40%
Direct labor	$236,160		12%
Treatment	$280,800		14%

Cost of Goods Sold		$1,301,760	67%

Gross Profit		$648,240	33%
Expenses			
Indirect Labor	$88,320		5%
Celerical	$28,000		1%
Salaries	$145,000		7%
Payroll taxes	$37,311		2%
Office supplies	$2,400		0%
Plant supplies	$58,500		3%
Benefits	$43,836		2%
Utilities	$78,000		4%
Phone	$2,400		0%
Insurance	$8,500		0%
Maintenance/Repair	$16,450		1%
Taxes	$16,897		1%

Operating expenses	$525,614		27%
Interest on operating expenses	$26,649		1%

Total operating expense		$552,263	28%

Operating profit		$95,977	5%
Other expenses			
Building Depreciation	$39,000		2%
Equipment Depreciation	$26,500		1%
Interest on long-term debt	$119,088		6%

Total other expenses		$184,588	9%

Net profit before Income Tax		($88,611)	-5%
		=======	

Cost per sq.ft. $25.30

Appendix B

Cost and Economic Considerations

The focus of the economic comparison of this study was to determine whether modern timber bridge decks are cost competitive with precast concrete bridge decks for short spans. The Mississippi Department of Transportation maintains data on bridge costs compiled from actual bridge projects in Mississippi each year. However, in practice, bridge costs are reported which include the total cost of the bridge. According to estimates from engineers with the Mississippi State Aid Road Department, the cost of the superstructure is approximately 50 percent of the total bridge cost for the pre-fabricated concrete bridge and 40 percent of the total bridge cost for a poured-in-place, pre-stressed beam span or a flat slab concrete span.

It was possible to get data on the deck cost only for the pre-cast concrete bridges because decks are manufactured by firms in a factory setting and sold separately to contractors and local governments. Modern timber bridge decks can also be manufactured in a factory setting and sold to the same customers.

Cost Comparisons

An attempt was made to compare the cost of bridge deck components using modern timber methods and using pre-cast concrete. To estimate the cost of the modern timber bridge decks, twelve Mississippi firms were asked to submit quotations for 18-, 20-, 24-, and 28-foot bridge spans. Specifications were provided to these firms. Two responded and the information provided by these two firms is presented in Table B1. The quotes are for the modern timber bridge decks only and do not include guard rails, substructure, transportation to the job site, or erection at the job site. Quotes for pre-cast concrete bridge decks were obtained from a private vendor and are included in Table B2.

While not the specific focus of this study, costs for spans in excess of 30 feet were also estimated. Quotes for timber glue laminated bridge decks of 30, 40, and 50 feet and longer were obtained from firms producing these lengths. For concrete construction, actual costs for 37 Federal Aid Project bridges were obtained from the State Highway Department.

Short Bridge Span Analysis

Bridge costs were analyzed by determining the cost breakdown on a per square foot basis (see Table B1). Timber bridge decks must be surfaced with asphalt or covered with clay gravel. Based on the quotations received, it was found that costs for decking only for modern timber bridge decks are $17.25 per square foot for the 18-foot span and increase to $33.43 per square foot for the 28-foot span.

A pro forma analysis of a hypothetical manufacturing plant for modern timber bridges was prepared and this analysis is presented as Appendix A. The analysis indicated through a cost build-up approach that an estimated selling cost of modern timber bridges could be in the $18 to $25 per square foot range for the business to operate successfully. This is based on the volume of modern timber bridge decks produced. This represents a cost for the bridge deck only, F.O.B. the factory. The product produced was assumed to be a 25-foot long by 26-foot wide bridge deck. These findings are consistent with the two quotes received from our solicitation from Mississippi firms indicating deck costs in the $16-$32 range.

Costs for pre-cast concrete bridge deck components were determined by obtaining a price list from Choctaw, Inc. These data are presented in Table B2. Costs were $11.03 per square foot for the 19-foot span and $13.41 per square foot for the longer 31-foot span. Again, this is for the deck only and does not include substructure or guard rails. It does, however, include transportation to the job site.

Longer Bridge Spans

Quotes for glulam timber bridge decks for 30-, 40-, and 50-foot spans were also obtained and are presented in Table B3. The deck material only for laminated timber bridges ranged from $28 to $36.37 per square foot. These figures represent the cost of the deck only and do not include substructure, guard rails, or transportation to the site.

Bridge engineers with the state highway program provided actual bridge construction costs for bridges built in Mississippi under the federal aid program. These costs are presented in Tables B4, B5, and B6. They represent the total bridge cost including substructure, bridge decks, and railings associated with the construction of the bridge, except for rip-rap material. Three concrete designs were used – pre-cast spans, pre-stressed beam spans, and modified pile spans. No modern timber bridges, other than demonstration bridges, were built in this period. In 1993, the per square foot costs of 37 bridges built on the Federal Aid Project ranged from $24.12 to $33.01 per square foot. For comparison with modern timber bridges, pre-stressed beam span designs using poured-in-place concrete decks can also be used for applications requiring spans in excess of 30 feet. The total cost of such designs (26-30 feet wide) using concrete ranged from $24.12 to $30.56 per square foot, including substructure, guard rails, and installation, as indicated in Tables B4, B5, and B6. A figure depicting the estimated costs of timber and concrete spans is presented as Figure B1.

Bridge Construction

Replacing bridges requires time to remove the old structure, drive new piling, prepare piers, and put the new structure in place. When one is comparing pre-fabricated modern timber bridge decks and pre-fabricated concrete decks, it appears that the time needed to replace a bridge using the two systems is approximately equal.

Bridge Quotes

Table B1. Timber Bridge Deck Cost Estimates

Vendor	Bridge	Timber	Treatment	Labor	Total	$/sq ft	Asphalt $/sq ft	Total	Wt.*
Company "A"	18x24	$3,383	$1,818	$1,818	$7,019	$16.25	$1.00	$17.25	30,550
Company "A"	20x24	$3,955	$2,088	$2,088	$8,131	$16.94	$1.00	$17.94	33,945
Company "A"	24x24	$6,380	$2,920	$2,920	$12,219	$21.21	$1.00	$22.21	44,272
Company "A"	28x24	$13,984	$3,902	$3,902	$21,788	$32.42	$1.00	$33.42	55,779
Company "B"	18x28	$4,094	$1,732	#N/A	#N/A	#N/A	$1.00	#N/A	35,642
Company "B"	20x28	$4,779	$1,923	#N/A	#N/A	#N/A	$1.00	#N/A	39,602
Company "B"	24x28	$8,144	$2,736	#N/A	#N/A	#N/A	$1.00	#N/A	51,651
Company "B"	28x28	$14,253	$3,690	#N/A	#N/A	#N/A	$1.00	#N/A	65,076

*includes wt. of asphalt

Table B2. Pre-Cast Concrete Bridge Deck Price

Vendor	Bridge	Total	$/sq ft	Wt.
Choctaw	19x26	$5,868	$11.03	65,744
Choctaw	31x26	$11,644	$13.41	106,584

Information provided by Choctaw, Inc. price list effective December 1, 1993

Table B3. Material Cost Estimates for Timber Glue Laminated Bridge Decks

Vendor	Bridge	Material	Subtotal	Asphalt	Total Deck Material
Company "C"	30x24	$19,440	$27.00	$1.00	$28.00
Company "C"	40x24	$27,360	$28.50	$1.00	$29.50
Company "C"	50x24	$38,400	$32.00	$1.00	$33.00
Company "D"	30x24	$21,276	$29.55	$1.00	$30.55
Company "D"	40x24	$32,378	$33.73	$1.00	$34.73
Company "D"	50x24	$42,447	$35.37	$1.00	$36.37

Table B4. 1993 Bridge Costs, Federal Aid Projects

Type	# built	Total cost/sq ft	Estimated substructure	Estimated superstructure
26 ft wide prestressed beam span	3	$24.12	$9.65	$14.47
28 ft wide prestressed beam span	18	$29.72	$11.89	$17.83
30 ft wide prestressed beam span	9	$26.16	$10.46	$15.70
28 ft wide precast span	3	$33.01	$16.51	$16.51
30 ft wide flat slab	3	$26.95	$10.78	$16.17

Information provided by Mississippi State Aid Road Department

Table B5. 1992 Bridge Costs, Federal Aid Projects

Type	# built	Total cost/sq ft	Estimated substructure	Estimated superstructure
26 ft wide prestressed beam span	2	$29.21	$11.68	$17.53
28 ft wide prestressed beam span	11	$27.58	$11.03	$16.55
30 ft wide prestressed beam span	4	$30.56	$12.22	$18.34
28 ft wide precast span	1	$25.42	$10.17	$15.52

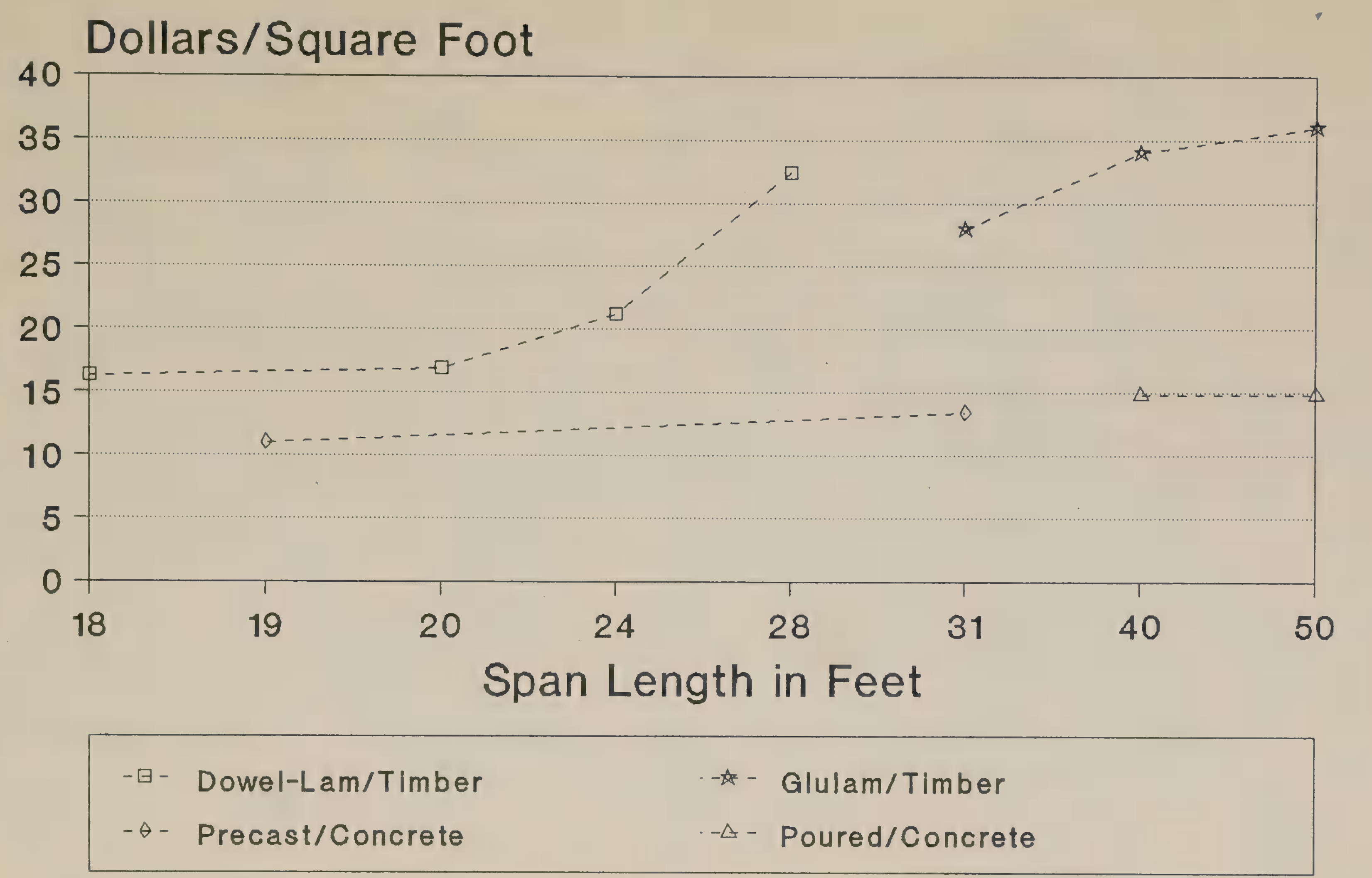
Information provided by Mississippi State Aid Road Department

Table B6. 1991 Bridge Costs, Federal Aid Projects

Type	# built	Total cost/sq ft	Estimated substructure	Estimated superstructure
26 ft wide prestressed beam span	2	$26.20	$10.48	$15.72
28 ft wide prestressed beam span	11	$28.30	$11.32	$16.98
30 ft wide prestressed beam span	2	$28.20	$11.28	$16.92
28 ft wide precast span	2	$27.72	$13.86	$13.86
28 ft wide flat slab	1	$30.61	$12.24	$18.37
30 ft wide flat slab	4	$38.30	$15.32	$22.98

Information provided by Mississippi State Aid Road Department

Figure B1. Estimated Cost of Bridge Deck



Poured/Concrete Costs Are Based On
Estimated Averages For All Span Lengths.

However, this is more a site-specific issue than a type-of-deck issue. Removal of the old bridge and preparing the substructure are the more time-consuming activities. Actually, placing the deck on the new supports can be done in several hours using a crew of 5-8 workers and a small crane for either modern timber bridge decks or pre-cast concrete bridge decks.

Economic Impact Comparisons

The relative impact on the economy of competing industries seeking to satisfy demands of the consuming public is at best a difficult determination. The specific issue addressed here is a comparison of the economic impacts on the Mississippi economy of using modern timber bridge decks, concrete decks, or some combination thereof to fulfill Mississippi bridge replacement infrastructure needs.

The question that remains to be answered is whether there are other economic factors that might offset these cost differentials. For example, if concrete bridges were being imported into Mississippi, thereby not using indigenous raw materials or Mississippi labor in the production process, it could be argued that developing an industry within the state (timber bridge construction, in this case) would create additional economic growth. This new industry and its growth would have "multiplier effects" throughout the economy, thus potentially offsetting the initial cost differentials.

An evaluation of the impact of expanding a particular industry, in this case timber versus concrete bridges, involves a number of factors. Three particularly important factors include: 1) to what extent are raw materials used in the process produced within the state's economy; 2) to what extent are the production processes transforming the raw material into final productions undertaken within the state; and 3) what is the differential impact of an expansion in each of these industries.

Responding to the first of these factors, raw material availability reveals that the necessary inputs for both concrete and timber bridges are readily available in the state. Mississippi, in fact, has notable timber and concrete raw material supplies, with established industries in both.

Secondly, to what extent are established industries available within the state to transform the raw materials into finished products (bridges). There are existing businesses in the state which manufacture pre-cast concrete bridge decks and construction firms which build bridges. However, while there are mills and treating plants in Mississippi capable of producing pre-fabricated modern timber bridge components, there are no facilities currently in operation. Thus, initially it is likely that the use of timber bridges would actually result in a leakage in the economy in that they would be imported from outside the state. However, there is reason to believe that if a demand for timber bridges were to develop that Mississippi suppliers would eventually emerge. Thus, over time both of these industries should be readily available within the state.

The answer to the third factor, to what extent are the two industries interrelated with the rest of the economy, can be addressed with the use of economic multipliers. Multipliers determine the economic impact of an expansion in a particular industry by quantifying the direct, indirect, and induced economic effects on the total economy of a change in final output demand in a specific industry sector.

For this purpose total linkage multipliers developed for the Mississippi economy are referenced (Lee). Total linkage multipliers for Sector 42 (Stone and Clay Products) and Sector 29 (Other Wood Products) can be used to ascertain the differential impacts of the two bridge types. Output, income, and employment multipliers for Sectors 42 and 29 respectively are: 1.79, 1.89, 1.99 and 1.99, 1.95, and 1.93. Because of the composition and deviation of multipliers for these two sectors, the resultant impact on the state's economy will essentially be the same. This is not unexpected since both bridge types utilize Mississippi raw materials, and either are or could be constructed within the state.

Summary

This study has shown that modern timber bridges are a technically viable design alternative. With additional research and design, modern timber bridge components may be able to compete on a cost basis with concrete deck systems as the industry develops and is able to reduce its costs through familiarity with the new technology and efficiencies in production. It appears, however, by our cost comparisons of only two modern timber bridge designs and one wood species, that concrete deck systems are presently the least expensive alternative.

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